Time, tone and the brain: Behavioral and neurophysiological studies on time reference and grammatical tone in Akan

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Frank Tsiwah

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CHAPTER 1

General Introduction

1.1. INTRODUCTION

In 2016, Donald Trump wins the American election. The most obvious thing likely to pop up in the mind of the reader of the above sentence is its grammatical oddness. This is mainly because the time frame of the verb *win* does not correspond to the specified temporal information '*in 2016*', which indicates that the event took place in the past. Time reference is essential for effective communication in every language of the world. Many languages such as those in the Indo-European group express time reference through morphological affixation whereas some Asian languages such as Chinese and Indonesian express time reference through aspectual adverbs. Interestingly, time reference is distinctively expressed in Akan (a tonal language belonging to the Kwa language family) by the use of grammatical tone (the use of tone to distinguish grammatical meaning).

While neurolinguistics studies have shown that time reference and lexical tone (the use of tone to distinguish lexical meanings in tonal languages) are problematic for individuals suffering from brain lesions in the left and/or the right hemisphere (Bastiaanse, 2013; Kadyamusuma, et al., 2011a), no study has yet ventured to investigate grammatical tone processing. The uniqueness of this dissertation lies in the fact that it sheds more light on tonal processing and time reference by providing further evidence from an understudied language, Akan, which uses tone for grammatical purposes. Research on grammatical tone is novel, and thus, this thesis will inform previous theories on linguistic tonal processing in the healthy and the damaged brain. This project will be executed by investigating adult Akan speakers with brain damage in the left (with aphasia) and the right hemisphere (without aphasia), as well as non-brain damaged speakers. The following sections will provide a general view of aphasia, an overview of the study of tense problems and the theories that explain time reference deficits in patients with agrammatic aphasia. This will be followed by a description of relevant aspects of the Akan language, and a review of various studies on tone processing in patient with left and right hemisphere brain damage, as well as healthy speakers. The motivation for the study will also be discussed in this chapter.

1.2. APHASIA: A GENERAL VIEW

The word aphasia was derived from the Greek 'αφατος'(aphatos), meaning 'speechlessness', and it was first used by Trousseau (1864). Aphasia is defined as a language disorder (not a speech disorder) as a result of a focal brain damage, particularly in the left hemisphere, caused either by a cerebral vascular accident (CVA: stroke), traumatic brain injury, an infection (such as encephalitis), or a brain tumor. In aphasia, production and comprehension of language, in all of its modalities (speaking, listening, reading and writing) are affected to a certain degree, depending on the locus and the severity of the lesion (Grodzinsky, 1990). According to the Western Aphasia Test (Kertesz, 1982) and the classification of the Boston Diagnostic Aphasia examination (BDAE; Goodglass & Kaplan, 1972; Goodglass et al., 2001), there are two main groups of aphasic syndromes, namely: fluent and non-fluent aphasias, with each group being associated with different loci as well as different linguistic impairments. Fluent aphasias include Wernicke's aphasia (producing phonemic and/or verbal paraphasias, neologisms, and impaired word and sentence comprehension) anomic aphasia (word finding difficulties), transcortical sensory aphasia (similar to Wernicke but with an intact repetition) and conduction aphasia (phonemic paraphasias, especially during repetition). Leaving fluent deficits aside, the non-fluent aphasias include Broca's aphasia, transcortical motor aphasia, and global aphasia, and the term 'non-fluent aphasia' is used to group a set of syndromes in which patients lose the ability to communicate fluently (Nestor, et al., 2003). The spontaneous speech of patients with non-fluent aphasia is characterized by effortful and telegraphic (mainly content words) speech production (if any production at all), word retrieval difficulties, phonological distortions, grammatical errors, and generally good comprehension (Bastiaanse & Jonkers, 1998). Non-fluent aphasia thus defined, is often referred to as 'agrammatic aphasia'. Among the cross-linguistically attested deficits in agrammatism, tense and time reference have received much attention, and the next section gives an overview.

1.3. THEORIES ON TENSE AND TIME REFERENCE IN THE BRAIN

In the 1990's, after a series of studies observing individuals with aphasia, some authors proposed that agrammatism is a structural deficit (Grodzinsky, 1995 for comprehension; Friedmann & Grodzinsky, 1997 for production). Hagiwara (1995) for comprehension and production) posited that the lower the position of a functional head and its projection in a syntactic tree, the more accessible it is to individuals with agrammatic aphasia. This means that verb inflections such as tense and aspect are susceptible to impairment in individuals with agrammatic aphasia because they are high in the syntactic tree. Based on the work of Pollock (1989), Friedmann and Grodzinsky (1997) also posited that the difficulties agrammatic patients show in producing tense (in the presence of a better-preserved agreement) can be attributed to their inability to access the tense node, which is higher on the syntactic tree than agreement. This led to the proposal of the Tree Pruning Hypothesis (TPH: Friedmann and Grodzinsky, 1997): when a node is inaccessible to agrammatic aphasics, all nodes above it are also inaccessible. Thus, an impairment in the Tense node implies impairment in the CP node as well (Friedmann, 2002).

However, studies within the last two decades have suggested a processing, rather than structural, deficit in agrammatism. Among the processing accounts is the Tense Underspecification Hypothesis (TUH) which was formulated by Wenzlaff and Clahsen (2004; 2005), proposing that tense is underspecified in aphasia. That is, it is not the position of tense on the syntactic tree that is impaired but rather the specification of the tense features (Wenzlaff & Clahsen, 2005). Another study on German agrammatism reported conflicting results: Burchert et al. (2005) reported a double dissociation – either tense or agreement (or both) are impaired in German agrammatic speakers. This finding led them to formulate the Tense and Agreement Underspecification hypothesis (henceforth TAUH). Another processing account that explains the underpinnings of tense inflection deficit in agrammatic patients is the Diacritic Encoding Retrieval hypothesis (henceforth DER; Faroqi-Shah and Thompson, 2007). The DER hypothesizes that a speaker needs to specify certain diacritic parameters (represented by inflectional affixes such as tense, mood and aspect) that encode temporal reference, before a message can be formulated. Other diacritic parameters, such as agreement, are not needed for message formulation, and, thus, are operationalized only during syntactic encoding, which occurs at a later stage, and hence, they tend to be better preserved.

So far, from the data discussed above, we can conclude, with one exception (TAUH) that the production of agreement is generally (better) preserved in agrammatic patients (Friedmann & Grodzinsky, 1997; Wenzlaff & Clahsen, 2004), whereas tense is more susceptible to impairment (Burchert et al., 2005; Friedmann & Grodzinsky, 1997; Bastiaanse, 2008; Gavarró & Martínez-Ferreiro, 2007). However, the theories discussed above cannot satisfactorily account for the dissociations across tenses that have been found in some studies – with past-referring tenses being more difficult to produce and comprehend than non-past tenses. Bastiaanse (2008) reported that both finite and nonfinite verb forms referring to the past were more difficult for Dutch agrammatic speakers to produce than verbs referring to the present. Additionally, some studies found that agrammatic aphasic speakers do not only have difficulties with tense but also with grammatical aspect, particularly the perfective aspect (Tsapkini et al., 2001; Stavrakaki & Kouvava, 2003). According to Bastiaanse (2008), the source of the tense inflection deficit in agrammatism cannot be attributed to tense per se but rather to time reference, particularly reference to the past, and, thus, any construction referring to the past will be relatively problematic for agrammatic speakers. This suggests that aspect, particularly perfective forms referring to completed event, should be more problematic in agrammatic speech.

Another piece of evidence for the time reference deficit in agrammatism comes from the study of Yarbay Duman and Bastiaanse (2009), on Turkish agrammatic speakers. Their study was set to investigate the origin of the verb inflection deficit in Turkish agrammatic speakers by testing verb forms that refer to the past and the future, including finite verbs and particles, in a sentence completion task in Turkish. They reported that the production of verbs referring to the past (past tense/perfective aspect) is harder for Turkish agrammatic speakers than verbs referring to the future (future tense/imperfective aspect). This suggests that it is not tense per se that is problematic for agrammatic speakers but rather the temporal reference nature of tense. Bastiaanse et al. (2011) and Bastiaanse (2013), based on an extensive cross-linguistic data on comprehension and production of time reference, have put forward a comprehensive model – the *Past Discourse Linking Hypothesis* (henceforth PADILIH), which accounts for why reference to the past is difficult.

1.3.1. The Past Discourse Linking Hypothesis (PADILIH)

Recapitulating the discussion on tense and agreement in agrammatic individuals, one of the influential accounts that addresses tense difficulties is that of Avrutin (2000, 2006). According to Avrutin, the processing of agreement is done by a purely morphosyntactic system which does not require any discourse operation, and thus, resolved within 'narrow syntax', while tense requires access to narrow syntax and 'discourse syntax', hence increasing the processing load on the brain (Avrutin, 2000). That is, in the computation of agreement, the syntactic operation is limited only to the 'local environment' which does not need any extra sentential information, and thus, is less costly, unlike tense, where computation is always between the sentence and the discourse. In his example "*in 1917, Lenin comes to power*" (Avrutin, 2000: 310), he states that the sentence is pragmatically odd, although it is syntactically acceptable. However, when the same sentence is presented in a specific historical context (such as a historical narration where the notion of past is already indicated), it becomes pragmatically acceptable. Thus, the acceptability of a particular tense form is dependent on the discourse, to some extent. Avrutin, therefore, claims that problems with tense should be more often observed than problems with agreement, in agrammatic aphasic patients' speech (Avrutin, 2000). Zagona (2003) makes the relation between discourse linking and tense more specific: that it, is not tense per se that is discourse linked, but verb tense that makes reference to the past. According to her, present verb tense is bound locally (within the sentence) – that is the time of speaking coincides with the time of the event and, hence, no discourse linking is required. Also, future time reference is categorized as a subclass of present tense, hence not discourse linked (Zagona, 2013). Thus, only past tense needs to be discourse linked.

Building on the idea of Avrutin (2000; 2006) and Zagona (2003, 2013), Bastiaanse et al. (2011) and Bastiaanse (2013) argue that all reference to the past through tense and/or aspectual adverb requires discourse linking, and thus, will be impaired. That is, reference to the past through free and bound grammatical morphemes, including periphrastic verb forms denoting perfect aspect that refer to a completed action (in Dutch *heeft gelopen*: lit. 'has walked') is relatively impaired. Bastiaanse and her colleagues captured this phenomenon in a theory termed as the Past Discourse Linking Hypothesis (henceforth: PADILIH). According to the PADILIH, when referring to the past, the time of speaking does not coincide with the event time, hence, a link between these two different time points has to be established. However, reference to the present requires that the time of speaking coincides with the time of the event, and hence, no discourse linking is required. In reference to the future, although the time of speaking and event time do not coincide, there is no discourse linking since the event has not yet taken place. Additionally, future reference is not bound within the sentence nor to the discourse. Bastiaanse (2013) follows Zagona (2013) and suggests that both the present and the future time reference could be paired as 'non-past', and thus, are assumed to be less costly.

The PADILIH accounts for the longer Reaction Time (RTs) for past verb forms in non-brain damaged individuals (Faroqi–Shah & Dickey, 2009) and selective impairment of past time reference which has been found in many studies with clinical populations across languages (Bastiaanse, 2008; Faroqi–Shah & Thompson, 2007; Yarbay Duman & Bastiaanse, 2009). The evidence gathered across languages suggest that time reference in individuals with agrammatic aphasia is compromised – and that reference to the past is more affected than reference to the present and future (Bastiaanse, 2013).

The predictions of the PADILIH in agrammatism are not only supported by evidence from monolingual aphasiological data but also by data on bilingual agrammatic aphasia speakers (Abuom et al. 2011; Abuom & Bastiaanse 2012; 2013). Abuom and Bastiaanse (2013) investigated the production and comprehension of time reference in both languages of Swahili-English bilingual agrammatic speakers. Interestingly, despite the vast morphological differences between Swahili and English, Abuom and Bastiaanse's (2013) findings showed an identical pattern of impairment in both languages. They found in both their production and comprehension that whenever the bilingual agrammatic speakers made errors, the past time reference was most affected, whereas time reference to both the present and the future were relatively intact, in both languages. However, reference to the past was worse in English than in Swahili. The authors argue that this may be related to morphological structure: Swahili has the most complex but also the most regular morphological system whereas English has both regular and irregular verb forms. Apparently, a regular system is more resistant to errors. These findings are consistent with evidence from another study by Abuom and Bastiaanse (2012) which investigated the use of verb inflections for tense and time reference in the spontaneous speech of Swahili-English agrammatic speakers, and reported that in both languages, reference to the past was more difficult than reference to the present.

A recent study has shown that the selective impairment of past time reference, as claimed by the PADILIH, is not restricted to agrammatism, but it is also attested in fluent aphasias. Bos and Bastiaanse (2014), examining the nature of time reference deficit, tested

Dutch agrammatic and fluent aphasic speakers' ability to use verb forms referring to the past, irrespective of tense. Agrammatic and fluent aphasic speakers showed an identical pattern in their performance, even though the former performed worse than the latter. Bos and Bastiaanse (2014) reported that irrespective of the finite verb tense, reference to the past (Dutch present tense auxiliary + participle, and simple past tense) is more impaired than reference to the present. The presence of a past time reference deficit in fluent aphasia individuals is consistent with the findings of a previous study by Jonkers and De Bruin (2009) who also showed that a past tense deficit affects Dutch Broca's and Wernicke's aphasic individuals alike.

Some studies using event-related potentials (ERPs; see Luck, 2005 for details of the technique) have also provided support for the PADILIH, suggesting that the processing of present and past time reference rely on qualitatively different neural representations (Baggio, 2008; Dragoy et al., 2012). According to Baggio (2008), the brain of healthy individuals evokes a Left Anterior Negativity (LAN: a brain response for morphosyntactic violations; see Neville et al., 1991) and a P600 responses (indicative of syntactic re-analysis and repair; see Friederici et al., 2002; Hagoort, 2003 for review) time-locked to the target verb for past time contexts violated by the present verb form. Dragoy et al. (2012) also found the P600 effect for violation by a present tense verb, although there was no evidence for the LAN. No P600 response for violation by a past tense verb was found. According to Dragoy and colleagues, these differences are in line with the predictions of the PADILIH – that is, when reference is made to a past time, which requires discourse linking, the processing load on the brain increases; this is not the case if reference is made to the present. Bos et al. (2013) also tested violations with periphrastic verb forms, with the goal of investigating whether the P600 brain response to tense violations is a result of tense per se or time reference. Their findings indicated that both simple verbs and periphrastic verb forms evoke a P600 in such contexts, and hence, it is time reference rather than tense that causes such differences.

1.3.2. Time reference in languages with aspectual and lexical adverbs

There is cross-linguistics attestation to the fact that time reference is impaired in agrammatism, and that reference to the past is more affected than reference to the present and/or future, in both production and comprehension in languages that express time reference through verb inflection. In some Asian languages, however, such as Mandarin Chinese and Thai, verbs are not inflected for tense and aspect to express time reference. The next question to ask is *whether past time reference is also impaired in languages with no verb inflections, but rather aspectual adverbs, such as Chinese and Thai?* If the problem is time reference and not verb morphology, it is expected that Chinese and Thai show a similar pattern as predicted by the PADILIH, even for agrammatic speakers of this group of languages.

Time reference in tenseless languages (Chinese and Thai)

Chinese uses optional free grammatical morphemes – aspectual adverbs, to make time reference. Even the aspectual adverbs could be dropped when the time frame is already assumed by the speaker and the listener in the context of discourse. For example;

(1a)	*Zhe ge ren*	*du*	***le***	*yi fong sin*
	the man	read[perfect]		a letter
	The man read the letter			
(1b)	*Zhe ge ren*	***zai***	*du*	*yi fong sin*
	the man	[progressive]read		a letter
	The man is reading the letter			
(1c)	*Zhe ge ren*	***yao***	*du*	*yi fong sin*
	the man	[future]read		a letter
	The man will read the letter			
	(Bastiaanse, 2013)			

From the above examples, the Chinese *le,* which is used post-verbally, indicates that an event has already taken place in the past and it is completed. The preverbal *zai* is used to express progressive aspect of an action whereas *yao,* which is also used preverbally, indicates an action referring to the future.

Bastiaanse et al. (2011) investigated time reference in English, Turkish and Chinese agrammatic aphasic speakers. Their results showed that in English and Turkish, past time reference was more impaired than present in both production and comprehension. In their comprehension experiment, Chinese agrammatic speakers performed worse on the past time frame than both the present and the future time frames. Surprisingly, in the production experiment, the performance of the Chinese agrammatic participants was poor across all conditions. Bastiaanse (2013) suggests that in Chinese, using a verb to indicate reference to time is by default discourse-linked because aspectual adverbs are only used when the time of the event is not clear from discourse, and these aspectual adverbs are always discourse linked. In addition, the use of an aspectual adverb in combination with a lexical adverb in Chinese is redundant, and therefore omitting an aspectual adverb still renders a sentence grammatical.

Similar to Chinese, Thai uses aspectual adverbs and/or free-standing grammatical morphemes to mark events that are completed, still ongoing, and yet to commence. While Thai present and past are indicated by the aspectual adverbs *kamlang* (e.g. *Chan kamlang kian*: "I am writing") and *leaw (e.g. Chan kian leaw:* "I wrote"), respectively, the future is represented by a grammatical morpheme that acts like a modal verb: *jaa* (e.g. *Chan jaa kian*: "I will write"). The aspectual adverbs and/or grammatical morphemes in Thai are used only when the time frame of an event is not clear in the context of the discourse. Siriboonpipattana et al. (2020) tested the pattern of impairment of time reference (present, past and future) in Thai speakers with agrammatic aphasia in a comprehension and production tasks. Their findings demonstrated that in both modalities, the agrammatic speakers showed more difficulties in reference to the future time than both present and past time frames. However, for their production task, the substitution error analysis showed that when the production of *yang mai*: "not yet" instead of the target word *jaa* is considered to be correct, the difference across the conditions disappears. Thus, the pattern observed in their revised data are in line with the data from Chinese (Bastiaanse et al. 2011).

Taken together, most of the cross-linguistic data of agrammatic speakers showing a selective impairment in past time reference, as predicted by the PADILIH, come from languages with verb morphology, where it is not possible to tease verb inflection apart from time reference. More importantly, testing time reference in both Chinese and Thai showed that the aspectual adverbs are discourse-linked in nature, and thus, are problematic for individuals with agrammatic aphasia. The next important question to ask is whether past time reference is also impaired in languages with neither verb inflections, nor aspectual adverbs, but rather grammatical tone, such as Akan.

1.4. THE AKAN LANGUAGE

Akan is a language spoken in sub-Saharan Africa, particularly Ghana, as well as in the eastern part of Cote d'Ivoire. It belongs to the Kwa group of the Niger-Congo language family. There are three main dialects of Akan namely: Asante Twi, Akwuapim Twi and Fante, with Asante Twi being the most widely spoken. All the three dialects are mutually intelligible. About 48% of Ghana's population of 24 million are native speakers of Akan (Ghana Statistical Service 2010). Nonetheless, an overall estimate of 80% of Ghanaians speak Akan as the first and/or second language. The native speakers of Akan are predominantly located in the Western, Central, Ashanti, Eastern, Brong Ahafo, and parts of the Volta regions of Ghana. A form of Akan is also spoken in some parts of the Caribbean, notably Suriname and Jamaica, as a result of the trans-Atlantic trade. In Ghana, the educational policy requires that a child can use his/her native language as the medium of instruction and communication until Grade 3 (Mfum-Mensah, 2005). In the southern part of Ghana, where Akan is spoken as the native language, children are taught to read and write in Akan, and by grade 3, children are expected to proficiently read and write Akan. From Grade 4 until tertiary level, English becomes the medium of instruction and Akan is then taught as a subject. Although English is the official language in Ghana, Akan is the most dominant language used in the media, trade, religion, political campaigns and day-to-day interaction among people. Linguistically, Akan has some distinctive features such as tone, vowel harmony, nasalization, and the phenomenon of serialization. The base word order of Akan is Subject Verb Object (SVO). The following sections will focus on Akan tonal structure and verbal morphology which form the essential part of this project. The Akan dialect under study is the Asante Twi, the most widely spoken dialect.

1.4.1. Tonal inventory of Akan

Akan is a tonal language. This entails that the meaning of an utterance in Akan depends not only on the vowels and the consonants that make up the words of an utterance, but also on the relative pitch with which each syllable of the utterance is produced (Dolphyne, 1988; Osam, 2003; 2008). Akan has two basic tones namely: High tone (H) and Low tone (L), and they are pronounced on a relatively level pitch (Dolphyne, 1988; Abakah, 2000). In Akan, tone has both lexical and grammatical functions.

Lexical tone in Akan

Akan, like some Eastern languages such as Chinese, has a lexical function of tone. That is, there are some minimal pairs in Akan that are distinguished solely on the basis of their tonal marking. Such minimal pairs, however, are limited in number in the Akan language (Dolphyne, 1988). The following are some examples of lexical tone in Akan:

(4a)	*pápá*	‘good’	(4b)	*dùà*	‘sow’
	pàpá	‘father’		*dùá*	‘tree’
	pàpà	‘fan’			

(4c)	*kàsá*	‘to speak’
	kásá	‘speech/language’

Grammatical tone in Akan

Unlike Asian tonal languages, tone in Akan is also used to mark certain grammatical categories such as tense and aspect.

Habitual Aspect

The Akan habitual aspect is marked by a high tone on the final syllable of a verb. Although the Akan habitual aspect does not locate a specific event in time, and, thus, cannot be referred to as the present tense, it is used to express present time and/or any indefinite time (Boadi, 2008). As a matter of fact, Boadi (2008) refers to the habitual as the Present habitual since it semantically connotes the idea of present time rather than the past.

(5a)	*Papa no*	*twèrɛ́*	*lɛ́tɛ̀*
	man the	write-HAB	letter.
	The man writes letter(s).		

(5b)	*Papa no*	*dí*	*àǹkàá*
	man the	eat-HAB	orange
	The man eats orange(s).		

The Akan past habitual, is represented by a clause initial particle 'na', indicating a past context.

(5c)	*Na*	*papa no*	*twèrɛ́*	*lɛ́tɛ̀.*
	PAST	man the	write:HAB	letter
	The man used to write letter(s).			

Progressive Aspect

Akan also has the present progressive aspect which is marked by the prefix "re-" in addition to the tonal marking. The prefix is realized differently across dialects. In the Asante Twi dialect, the progressive marker "re-" is realized as a vowel assimilated from the vowel in the preceding syllable (Osam, 2003). The vowel marking the progressive time becomes covert when expressed verbally. For example;

(6a)	*Papa nó*	*(ó)twèrɛ́*	*lɛ́tɛ̀*
	man the	PROG:write	letter
	The man is writing letter(s).		

(6b)	*Papa nó*	*(ó)dí*	*àǹkáá*
	man the	PROG:eat	orange
	The man is eating orange(s).		

Even though the Akan progressive has a present time connotation, it can also indicate a past imperfective aspect depending on the temporal adverb and the context of the discourse (Osam 2004). In this case the morpheme 'na' is used to put the progressive verb in a past context. For example:

(6c)	*Na*	*papa nó*	*(ó)dí*	*àǹkàá*
	PAST	man the	PROG:eat	orange
	The man was eating orange(s).			

Past tense

The Akan past tense is indicated by a suffix whose realization is dependent on whether the verb is followed by a direct object or not. When a verb is followed by a direct object or an adverbial, the final vowel of the verb stem is prolonged to indicate past if the verb ends in a vowel; and the final vowel then has a low tone (Osam, 2003). If the verb ends in a consonant and it is followed by a direct object (as in 7b), the final consonant is prolonged with a low tone. For example;

(7a)	*Papa no*	*twèrɛ́ɛ̀*	*lɛ́tɛ̀*
	man the	write:PAST	letter
	The man wrote letter(s).		

(7b)	*Papa*	*no*	*kàǹ-ǹ*	*lɛ́tɛ̀*	*no*
	man	the	read:PAST	letter	the
	The man read the letter.				

When the verb occurs at the clause final position, the suffix *-yɛ/-ɛ* is used, which is preceded by the prolongation of the final vowel of the verb.

(7c)	*Papa no*	*twèrɛ́ɛ̀-yɛ̀*
	man the	write:PAST
	The man wrote (it)	

Future tense

The future tense in Akan is morphologically marked by the prefix *bɛ́-/bé* with a high tone. The use of the future tense asserts that the event described by the verb will take place after the time of speaking. For example:

(8a)	*Papa*	*no*	*bɛ́twérɛ́*	*lɛ́tɛ̀*
	man	the	FUT:read	letter
	The man will read letter(s).			

(8b)	*Papa*	*no*	*bédí*	*àǹkáá*
	man	the	FUT:eat	orange
	The man will eat orange(s).			

A structural comparison between the Akan verb forms (discussed above) indicate that even though both the Akan present habitual and the present progressive aspects are indicative of present time, the latter is marked by a prefix in addition to tone (as in 6a), while the former is marked purely by tone (as in 5a). They both have the same tonal marking – Low (L) High (H), but they differ in their morphological structure (presence of a prefix in the present progressive aspect). The difference between the habitual and the past is indicated solely by tone. Whereas the tonal marking on the verb for the present habitual aspect on a disyllabic verb is Low – High (5a), the past has a Low-High-Low tone, with a prolonged vowel (as in 7a). The future verb form is marked by a High-High tone pattern when the verb is monosyllabic (as in 8b), and High-High-High when the verb is disyllabic (as in 8a). The next section provides a review of studies on tone, which have mainly focused on lexical tone.

1.5. A REVIEW OF LITERATURE ON TONE PROCESSING

Most of the languages in the world are tonal in nature (Fromkin & Rodman, 1993). In Africa alone there are more than 1000 tonal languages, yet most of the neurolinguistics studies that have been done on linguistic tone have focused on those spoken in Asia, such as Mandarin and Cantonese Chinese (Yiu & Fok 1995; Liang & Heuven, 2004), Thai (Van Lancker, 1980; Gandour et al., 1992a) and Norwegian (Moen, 2009), leaving African tonal languages less explored. Typologically, tonal languages in Africa are different from those spoken in Asia and Europe in terms of tone inventories and rule systems (Gandour, 2006). This data asymmetry has made it challenging to formulate theories that can be generalized to African tonal languages. One illustrative example is Akan, which has both lexical and grammatical functions of tone, with the latter being non-existent in any of the Asiatic tonal languages investigated so far. Although there have been a number of descriptive studies on lexical tones in some African languages, there is only one experimental study focusing on lexical tone processing in brain damaged speakers of Shona – an African language spoken in Zimbabwe (Kadyamusuma et al., 2011a; 2011b). And nothing is yet known about the neurolinguistics aspects of grammatical tone.

1.5.1. Hemispheric roles in tonal processing

Over the last couple of decades, researchers have shown a considerable interest in exploring the contributions of the left (LH) and right (RH) hemispheres to the processing of prosodic information. Most studies have shown that the left hemisphere is more involved in the processing of phonemic units such as phonemes, syllables, and words, while the right hemisphere is specialized for melodic, prosodic and affective (e.g. music, pitch contours) processing (Van Lancker, 1980; Kimura, 1961; 1964). The study of speech prosody processing in the brain dates back to the work of Monrad-Krohn's (1947), who investigated a woman who had difficulties in producing the phonemic tone contrasts in her native Norwegian dialect after brain damage, even though her ability to sing was not affected. The use of tonal languages has provided the possibility to examine the interplay between the functions of these two hemispheres, since pitch variations in tonal languages are significantly relevant to signal both linguistic and emotional information (Gandour, 2006). Various methods have been used to observe the functions of the two hemispheres in tonal processing. These methods include dichotic listening, neuroimaging, electroencephalography and brain lesion behavioral methods.

Dichotic listening studies on tone

In dichotic listening, two verbal stimuli are presented to both the left and the right ears simultaneously. However, information is received either solely or predominantly by one hemisphere. Presentation of linguistic stimuli often yield a right ear advantage (REA), when participants are asked to report what was presented in a trial (Kimura, 1961). The REA is an indication that the contralateral auditory pathways suppress the ipsilateral pathways at the level of the brain stem, thus favoring the right ear input to the language-dominant left hemisphere (Gandour, 2006; Kimura, 1967). However, the processing of music or pitch contours in nonlinguistic contexts show a left ear advantage and is, therefore, attributed to the right hemisphere (Zatorre et al., 2002; Friederici & Alter, 2004). Interestingly, pitch contours are processed in the left hemisphere when they involve differences in meaning at the word level. For instance, in previous research using the dichotic listening paradigm, lexical tone perception by native speakers of tonal languages shows a REA for tone processing, thus indicating the involvement of the left hemisphere (Van Lancker, 1980; Wang et al., 2004; 2001).

Evidence from a number of cross-linguistics studies using dichotic listening has shown consistent results for the REA for lexical tone processing. Van Lancker (1980) tested native speakers of Thai (a tonal language) and English (non-tonal language), who were either musically trained or untrained. The study included 3 conditions: minimal pairs distinguished by tone, minimal pairs distinguished by initial consonant, and a set of hums distinguished by pitch changes that were similar to those in the minimal pairs distinguished by tone alone. The English group, independent of musical training, showed a REA for minimal pairs differentiated by their initial consonants, but not for the minimal pairs distinguished by tone, since the former serves a linguistic function in English whereas the latter does not. The Thai group, however, showed a REA for words differentiated by both their initial consonants and the tone minimal pairs. As expected, hums did not reveal ear advantage: hums do not serve any linguistic purpose, hence, no ear advantage was observed in either of the language groups. These findings indicate that for native speakers of tonal languages such as Thai, tonal contrasts, but not hums, are predominantly processed in the left hemisphere, whereas for native speakers of non-tonal languages, tonal contrasts as well as hums are treated as linguistically irrelevant information, and, thus, are not processed in the left hemisphere.

Wang et al. (2004) also investigated hemispheric lateralization of Mandarin tone among four groups of listeners: native Mandarin listeners, English–Mandarin bilinguals, Norwegian listeners with experience with Norwegian tone, and American-English listeners with no tone experience. They observed a left-hemisphere advantage (as shown by REA) for the processing of Mandarin tones by native Chinese speakers. Similarly, the English–Mandarin bilinguals exhibited a left-hemisphere (a REA) dominance. However, there was no ear advantage in processing Mandarin tone by the Norwegian listeners, despite their experience with tonal contrasts in Norwegian. Also, for the American-English listeners without any tone background, no hemisphere advantage was observed.

Taken together, there is no ear advantage for native speakers of non-tonal languages such as American English, and for Norwegian listeners (who have experience with Norwegian tone but not with Mandarin tones) when they were asked to perceive Mandarin (Wang et al., 2001; 2004) or Thai (Van Lancker & Fromkin, 1973) lexical tones. This suggest that hemispheric lateralization is dependent not only on whether a unit, such as pitch, forms part of the speaker's linguistic system but also the speaker's experience with a particular language. In conclusion, the left hemisphere is dominant for the processing of pitch in lexical tone among native speakers of tonal languages but not for speakers of non-tonal languages. However, since lexical tones connote linguistic properties such as word meaning as well as pitches that sound melodic, the question is whether the above findings on prelexical processing of tone are confounded with lexical-semantic processing (Wong, 2002). This long-standing debate regarding the hemispheric lateralization of lexical tones has resulted in a large body of studies using neuroimaging techniques such as functional MRI (fMRI) or positron emission tomography (PET) (Gandour et al., 2002; Wong et al., 2004).

Neuroimaging Studies on Tone Processing

In the last two decades, data from functional neuroimaging studies have been quite promising in yielding a clearer picture of the neural mechanisms involved in tonal processing. Methods such as fMRI, PET and MEG have been adopted to examine the hemispheric lateralization of lexical tone processing in the brain. Most of the neuroimaging studies (such as PET and fMRI) have shown that in tonal languages, a pitch connoting linguistic information such as semantics is predominantly processed in the left hemisphere of native speakers (Gandour et al., 2002; Wong et al., 2004).

Gandour, et al. (2002) investigated whether the neural mechanisms that underlie functional asymmetries in speech processing are acoustic or linguistic in nature by using fMRI. They asked Thai and Chinese subjects to perform discrimination tasks of pitch and timing patterns presented in the same auditory stimuli in two different contexts: a linguistic context made up of Thai speech (T = Thai tones; VL = Thai vowel length), and a nonlinguistic context made of nonspeech hums (P = Pitch contours; D = duration). The Thai group showed activation in the left inferior prefrontal cortex in speech minus nonspeech contrasts for spectral (tone minus pitch contours) and temporal (vowel length minus duration) information, suggesting that the linguistics aspects of pitch and duration are unique to Thai listeners because they perceived them as having linguistic properties. However, regardless of language experience, both Thai and Chinese groups exhibited similar fronto-parietal activation patterns when judging nonspeech hums for either spectral or temporal cues (pitch contours minus vowel length, duration minus vowel length), indicating that the language-specific effects disappear when stimuli are purely acoustic in nature. According to Gandour and colleagues, the differences in brain responses (Thai vs Chinese groups) associated with Thai tones and vowel length indicate that hemispheric specialization is sensitive to language-specific, prosodic functions in addition to low level acoustic features. Thus, lower level specialization for acoustic cues in the spectral and temporal domains cannot be generalized to abstract higher order levels of phonological processing (Gandour et al., 2002).

Wong et al. (2004) used PET to compare the brain responses of native Mandarin and English-speaking listeners in discriminating pitch patterns embedded in Mandarin and English word pairs, and also passively listening to the same sets of stimuli. Their findings showed that whenever pitch patterns had a lexical function (for the Mandarin speakers), brain activations were predominantly in the left hemisphere, particularly the left anterior insular cortex – which has been shown to be active during language tasks. When native Mandarin speakers discriminated the same pitch patterns embedded in English words, activations were primarily in the right hemisphere, including the inferior frontal gyrus, which has been found to be active during pitch processing. When English speakers discriminated pitch patterns of English word pairs without a lexical function, the right hemisphere, including the right inferior gyrus, was strongly activated. Based on these findings, Wong and colleagues (2004) concluded that the brain activations associated with pitch perception depend on the function of those stimuli, and determined that the left anterior insula is especially responsive for lexically distinctive prosodic information such as lexical tone.

These data have been captured in a comprehensive model that integrates the acoustic and the linguistic processing of lexical tone: The right hemisphere is sensitive to low-level acoustic processing and the left hemisphere is sensitive to high-level linguistic processing (see Zatorre & Gandour, 2009 for a review). However, although the spatial neural mechanisms and the hemispheric lateralization underlying the perception of lexical tones have been extensively investigated, the temporal resolution of the processing of low-level acoustic information and the high-level linguistic information of lexical tones, has not been carefully examined with these techniques.

Electrophysiological studies on Tone Processing

In recent years, there have been a number of electrophysiological studies which have demonstrated that in addition to language experience, the neural mechanisms and the hemispheric lateralization involved in pitch processing are largely modulated by the linguistic relevance of the auditory input. Consistent with the neuroimaging studies discussed above, electrophysiological studies have demonstrated a right-lateralized pre-attentive processing of lexical tone (Luo et al., 2006; Chandrasekaran et al., 2007; Ren et al., 2009), suggesting that the auditory processing of lexical tones is shaped mainly by acoustic properties at a pre-attentive processing stage (Chandrasekaran et al., 2009). Most (if not all) of the electrophysiological studies have adopted Mismatched Negativity (MMN) to investigate pitch level and pitch contour at the pre-attentive stage of the auditory system. The MMN is a scalp-recorded, event-related brain potential that reflects detection of early cortical stages of auditory processing regardless of whether the participant is paying attention or not (Näätänen, 2001; Näätänen et al., 2007). The MMN has been found to reflect a left lateralized long-term memory traces for the lexical tone (Yue et al., 2014).

Luo et al., (2006) demonstrated right-lateralized mismatch negativities (MMNs) for early pre-attentive processing of lexical tone, suggesting that at the pre-attentive processing stage, the auditory processing of linguistic pitch functions as an acoustic unit (Chandrasekaran et al., 2009). They presented native Mandarin Chinese speakers with a meaningful auditory word with a consonant-vowel structure and infrequently produced word, either with a different lexical tone (as the deviant stimulus) or a different initial consonant (as the deviant stimulus) to create a contrast resulting in a change in word meaning. Their results demonstrated a stronger mismatch negativity response to lexical tone contrast at the pre-attentive stage, in the right hemisphere, as opposed to the left hemisphere lateralization for the processing of a consonant. Luo and colleagues put forward a two-stage model in processing linguistic pitch contours: a pre-attentive stage of processing involved in a lower-level pitch analysis in the right hemisphere, and an attentive stage of processing driven by higher-level linguistic representations with activation of neural circuits lateralized to the left hemisphere. This two-stage model of processing has been replicated in many other studies which have investigated the pre-attentive stage of processing lexical tones (Ren et al., 2009; Tsang et al., 2011). Surprisingly, these findings, that MMN lateralization is to the right hemisphere, conflict with the claim that MMN is lateralized to the left hemisphere (Näätänen, et al., 2007).

However, recent neurophysiological studies on categorical perception of lexical tone in native speakers of Mandarin Chinese have shown a parallel processing of acoustic and phonological information (Xi et al., 2010; Yu et al., 2014; Yu et al., 2017), rather than the independent processing mechanism proposed by Luo et al., (2006). Xi et al. (2010), by examining the categorical perception (i.e. the ability of native listeners to perceive continuous acoustic signals as discrete linguistic representations) of lexical tones using MMN, found a hemispheric difference in the processing of acoustic information (auditory processing) and higher-level linguistic information (phonological processing), hence replicating previous findings (Luo et al., 2006; Ren et al., 2009; see Zattore & Gandour 2009 for a review). Nevertheless, Xi and colleagues also demonstrated that acoustic processing and linguistic processing show an interaction between the two hemispheres at an early stage. Pitch analysis and a higher-level linguistic information were found to be activated in parallel within the short MMN time window for lexical tone perception.

Evidence from brain lesion studies

From the studies discussed above, acoustic processing such as pitch involves the right hemisphere whereas the processing of phonological information recruits the left hemisphere. There are other data that indicate that right hemisphere damage leads to a disturbance in pitch (F0) processing such as in intonation and stress (Baum & Pell 1997;

Behrens, 1989), even though the left hemisphere has been found to be dominant for processing linguistic F0 (Danly & Shapiro, 1982; Gandour et al., 1992).

Lesion studies that have investigated lexical tone processing in aphasia have mainly focused on perception and/or production of lexical tone, which have both been found to be prone to impairment. However, the degree of impairment seems to be different for perception and production, with the former being more disrupted than the latter (Yiu & Fok, 1995; Gandour et al., 1992; Gandour & Dardarananda, 1983; Kadyamusuma et al., 2011a; Moen & Sundet, 1996). Yiu & Fok (1995) demonstrated that Cantonese tone processing is disrupted in individuals with aphasias while it is intact in dysarthric patients, hence the tone processing deficit could be attributed to the lesion sites (especially in the left hemisphere) that result in aphasia. They also reported that Chinese aphasic speakers produce more tonal paraphasias than consonant or vowel paraphasias. This is consistent with the findings of Liang and Van Heuven (2004), who examined the speech of a Chinese female speaker (PYF) with left hemisphere brain damage and found that her production of lexical tones was more disrupted than production of vowels. Based on their findings, Liang and van Heuven (2004) suggested a separate function and localization for segmental and tonal aspects of lexical entries in tonal languages.

Kadyamusuma, De Bleser and Mayer (2011) also investigated the ability of brain-damaged individuals with left hemisphere damage and right hemisphere damage to identify lexical tone in Shona, a Bantu language spoken in Zimbabwe. Kadyamusuma and colleague's findings for lexical tone perception indicated that the performance of individuals with left hemisphere damage was poorer than that of the individuals with right hemisphere damage, which was in turn lower than the non-brain-damaged individuals who performed at ceiling. The difference between the left and right hemisphere damaged individuals is consistent with previous findings in other tone languages such as Chinese and Thai (Yiu & Fok, 1995; Gandour & Dardarananda, 1983). In Kadyamusuma and colleagues' production experiment, both the LHDs and the RHDs performed worse than the healthy participants. The production results suggest that both hemispheres are involved in the production of lexical tone, whereas the difference found between LHDs and RHDs in perception supports the claim that the left hemisphere is dominant for lexical tone perception. Further, the lower performance of the RHD relative to the performance of the non-brain damaged individuals suggests that both hemispheres are involved in tone perception, at least in the case of Shona lexical tone. Taken together, there is a bilateral processing of lexical tone in tonal languages, with the left hemisphere being dominant (Kadyamusuma et al., 2011a; 2011b).

So far, all the studies on tonal processing in damaged and healthy brains have focused on lexical tone, leaving grammatical tone an untapped area of research. Thus, it is not known how grammatical tone is processed by the human brain. Therefore, it is worthwhile to investigate Akan, which has grammatical tone. The next section provides the issues that are going to be addressed in this project.

1.6. THE CURRENT DISSERTATION

1.6.1. Issues to be addressed

The current project focuses on examining grammatical tone and time reference in Akan. The following topics will be addressed in this thesis:

1. The first issue this project seeks to address is grammatical tone processing in Akan speakers with left (agrammatic aphasia) and right hemisphere brain damage. The question is: Is grammatical tone perception disrupted in left and/or right hemisphere damaged speakers of Akan, as it has been found for lexical tone in other languages? For this, Akan left and right hemisphere damaged individuals will be included and they will be compared on impairment patterns in two tasks: when pitch is used for linguistic functions (such as grammatical tone) and for non-linguistic purposes (pure tone perception). So far, no study has examined how brain damaged individuals perceive grammatical tone.
2. The second issue to be addressed is whether the observed differences in past versus non-past time reference are restricted to languages with morphological verb affixations, or that they are also manifest in languages that express time reference through grammatical tones. According to the predictions of the PADILIH, Akan speakers with agrammatic aphasia should have difficulties with reference to the past, although there is no affixation, since the deficit is claimed to affect discourse linking and not tense morphology. This will be further investigated by examining whether an impairment (if any) in time reference in Akan could be decoupled from the effect of tonal markings on Akan verbs.
3. Lastly, this project will address the question of how temporal information in a grammatical tone language such as Akan is processed online. That is, to what extent is the neural representation of temporal processing in a grammatical tone language similar or different from the morphosyntactic processing of tense reported for Indo-European languages. Another question is: do the neural mechanisms for past and non-past time reference violations in a grammatical tone language differ? These questions will be addressed by using the event-related potential (ERP) technique.

1.7. OUTLINE OF THE DISSERTATION

The chapter 2 of this dissertation addresses the issue of whether Akan speakers with left and right hemisphere brain damage have impairments in perceiving grammatical tone, and how those impairments (if any) relate to the deficit that has been described for lexical tone perception. The study also aims at comparing the performance of these two patient groups on linguistic and non-linguistic tone perception tasks. Since there has not been any study yet on grammatical tone perception in these two patient groups, the findings of this study will contribute to the on-going discussion on the hemispheric lateralization of tonal processing.

Chapter 3 tackles the second issue raised in the previous section. That is, whether the past and non-past time differences observed in languages with morphological verb inflections can be extended to languages that use grammatical tone to make time reference. The study described in this chapter includes both a sentence completion (production) and a sentence picture matching tasks on time reference. Additionally, since Akan is a tonal language, a pure tone discrimination task was also used as a pretest, to examine the effect of tone (if any) on time reference processing. Akan speakers with agrammatic aphasia and no brain damage were recruited for this study. This study will give more insight into whether the problems agrammatic aphasic individuals have with time reference could be attributed to morphological inflections per se, or the notion of time.

Chapter 4 addresses the third issue raised in the previous section. This study uses Event-Related-Potentials (ERP) to investigate the neuronal underpinnings of temporal (dis)agreement processing in a grammatical tone language, and how they compare to morphosyntactic processing of tense reported for Indo-European languages. Additionally, it will be discussed whether the neural mechanisms for past and non-past time violations in a grammatical tone language differ.

Chapter 5, which is the general discussion chapter, will link the results of all the studies conducted for this dissertation. Here, the research questions will be answered, and recommendations will be made for future research.

CHAPTER 2

Perception of grammatical tone in Akan patients with left and right hemisphere brain damage[1]

ABSTRACT

It remains a matter of debate what roles the left and right hemispheres play in processing speech prosody. Brain lesion studies have demonstrated that lexical tone perception among native speakers of tonal languages is more disrupted in left hemisphere damaged (LHD) individuals than right hemisphere damaged (RHD) individuals. This has been taken to suggest that linguistically-relevant prosodic cues are predominantly left-lateralized, whereas non-linguistic stimuli are predominantly right-lateralized. However, this phenomenon has only been examined in lexical tone, leaving grammatical tone perception unexplored. The aim of this study was twofold: Firstly, to examine how individuals with LHD and RHD perceive grammatical tone, and secondly to compare grammatical tone to non-linguistic tone perception. Therefore, native Akan speakers with LHD, RHD and no-brain damage (NBD) controls were tested in two discrimination tasks that examined linguistic and non-linguistic tone perception. The results showed that while both the individuals with LHD and RHD show impairment in grammatical tone perception. Nonetheless, for non-linguistic tone perception, individuals with LHD outperformed the RHD individuals, although both had reduced performance compared to the NBD individuals. We conclude that there is potentially a bilateral involvement of the two hemispheres in grammatical tone processing, with the left being the dominant hemisphere. Therefore, theories of hemispheric lateralization of speech prosody should not seek a simple dichotomy between the two hemispheres, but rather an integrative one.

Keywords: Grammatical tone, non-linguistic tone, brain damage, hemispheric lateralization, Akan

1 This chapter has been adapted from: Tsiwah, F., Lartey, N., Amponsah, C., Popov, S., & Bastiaanse, R. (in review). Perception of grammatical tone in Akan patients with left and right hemisphere brain damage. *Journal of Neurolinguistics*.

2.1. INTRODUCTION

Research on the neuronal underpinnings of speech prosody processing dates back to Monrad-Krohn's (1947) study, that investigated a woman who had difficulties in producing phonemic tone contrasts in her native Norwegian dialect after left hemisphere brain damage, even though her ability to sing was unaffected. Over the last several decades, the issue of the distinct roles that the left and the right hemispheres play in speech perception has received considerable attention in the literature. Most studies have shown that the left hemisphere (LH) is more involved in the processing of phonemic units such as phonemes, syllables, and words, while the right hemisphere (RH) is specialized for melodic, prosodic and affective (e.g. music, pitch contours) processing (Kimura, 1961, 1964; Van Lancker, 1980; Zatorre & Belin, 2001). The use of lexical tone (i.e. when tone is used to distinguish lexical meanings) in tonal languages has provided significant insights into understanding the interplay between the functions of the two hemispheres in speech perception (Gandour, 2006). This is because pitch variations in tonal languages are relevant to signal both linguistic (differences in lexical meaning) and acoustic (e.g. pitch contour) information (Gandour, 2006). However, while a large number of studies have examined the hemispheric roles in lexical tone perception (Gandour et al., 1992; Gandour et al., 2002; Gu et al., 2013), the neural underpinnings of grammatical tone perception have not been uncovered to date. This study aims to address this gap in the literature by examining tone perception in left and right brain damaged speakers of Akan, a tonal language that uses tone for grammatical functions.

2.1.1. Hemispheric lateralization in lexical tone processing

The precise mechanism underlying the hemispheric asymmetry for speech prosody remains controversial. The two dominant accounts proposed for the hemispheric asymmetry of human pitch perception are the *function-dependent brain asymmetry* and the *acoustic-dependent brain asymmetry* models. The function-dependent brain asymmetry model, on the one hand, predicts LH lateralization when pitch information such as tone or intonation are used for linguistic purposes (Gandour et al., 2000; Van Lancker, 1980; for a review, see Zatorre & Gandour, 2008). For instance, processing of lexical tone will be left lateralized since in this case tones are used to provide semantic information at the word level (Gu et al., 2013; Xi et al., 2010). The acoustic-dependent brain asymmetry model, however, predicts RH lateralization of lexical tone because pitch information is processed on the basis of the acoustic signals it provides, irrespective of its functions (Ge et al., 2015; Poeppel, 2003; Ren et al., 2009; Sidtis & Van Lancker-Sidtis, 2003; Van Lancker & Sidtis, 1992; Zatorre & Belin, 2001).

This long-standing debate regarding hemispheric lateralization of lexical tones has resulted in a large body of studies using a wide range of methods such as dichotic listening, neuroimaging, and behavioral testing in brain lesioned individuals, to observe the functions of the two hemispheres in tonal processing. In dichotic listening studies, in which two verbal stimuli are presented to both the left and the right ears simultaneously, presentation of linguistic (tonal) stimuli often yields a right ear advantage among speakers of tonal languages, thus indicating processing in the language-dominant left hemisphere (Gandour, 2006; Kimura, 1967; Wang et al., 2004). However, cross-linguistics studies have shown that there is no right ear advantage for native speakers of non-tonal languages listening to lexical tone stimuli (Van Lancker & Fromkin, 1973; Wang et al., 2001; 2004). That is, the left hemisphere is dominant for the processing of pitch in lexical tone among native speakers of tonal languages, but not for speakers of non-tonal languages. This modulatory effect of language experience in functional brain asymmetry has been replicated in studies (Gandour et al., 2002; Wong et al., 2004) that have used functional Magnetic Resonance Imaging (fMRI), positron emission tomography (PET) and Event-Related Potentials (ERPs).

In an fMRI study, Gandour et al. (2002) presented Thai speech (varying pitch and vowel duration) and non-speech stimuli (hums with varying pitch contour and duration) to both Thai and Chinese speakers and found activation in the left inferior prefrontal cortex in the speech condition for the Thai group only. This suggests that the linguistics aspects of pitch and duration were unique to Thai listeners because they perceived them as having linguistic properties. However, regardless of language experience, both Thai and Chinese groups exhibited similar right fronto-parietal activation patterns when judging nonspeech hums for both spectral and temporal cues, indicating that language-specific effects disappear when stimuli are purely acoustic in nature.

Consistent with the neuroimaging data, electrophysiological studies have also demonstrated a right-lateralized pre-attentive processing of lexical tone (Chandrasekaran, et al., 2007; Gu et al., 2012; Luo et al., 2006; Ren et al., 2009), suggesting that the auditory processing of lexical tones is shaped mainly by acoustic properties at a pre-attentive processing stage (Chandrasekaran et al., 2009). Consequently, Luo et al. (2006) proposed a two-stage model for processing linguistic pitch contours: a pre-attentive stage of processing involved in a lower-level pitch analysis in the right hemisphere, and an attentive stage of processing driven by higher-level linguistic representations with activation of neural circuits lateralized to the left hemisphere. However, recent neurophysiological data on lexical tone perception in native speakers of Mandarin Chinese have shown parallel processing of acoustic and phonological information (Xi et al., 2010; Yu et al., 2014; Yu et al., 2017), contrary to the serial processing mechanism proposed by Luo et al., (2006). Further, a recent meta-analysis found support for convergent activation in bilateral inferior prefrontal and superior temporal regions as well as the right caudate during lexical tone perception in tonal languages (Kwok et al., 2017). In sum, the literature shows mixed results regarding hemispheric lateralization of lexical tone processing using brain imaging techniques.

Turning now to brain lesion studies, it has been cross-linguistically attested that both individuals with brain damage to the left hemisphere (LHD) and right hemisphere (RHD) show impairments in lexical tone processing, with the former performing worse than the latter (Gandour & Dardarananda, 1983; Packard 1986; Gandour et al., 1992; Baum & Pell 1997; Kadyamusuma et al., 2011a; 2011b). Gandour and Dardarananda, (1983) observed that Thai speaking individuals with LHD demonstrated more difficulties in distinguishing Thai words that differed only in tone than individuals with RHD, who were in turn less accurate than the non-brain damaged speakers. Similarly, Moen and Sundet (1996) showed that Norwegian speakers with LHD were impaired in their identification of two Norwegian tones (pitch accents), whereas such impairment was not apparent in the RHD group. Yiu and Fok (1995) also demonstrated that Cantonese tone processing was disrupted in LHD individuals with aphasias, while it was intact in speakers with dysarthria. Thus, tone processing deficits are associated with lesion sites (especially in the left hemisphere) that result in aphasia. However, Yui and Fok did not include individuals with RHD. Note that much of the data on tone processing in clinical population (as discussed above) come from tonal languages spoken in Asia. There are only two studies that have examined lexical tone processing in individuals with unilateral brain damage in an African tonal language, Shona, a Bantu language spoken in Zimbabwe (Kadyamusuma et al., 2011a; 2011b). Kadyamusuma et al. (2011a) showed that for lexical tone perception, Shona speaking individuals with left hemisphere damage were poorer than individuals with right hemisphere damage, who were in turn lower than the non-brain-damaged individuals who performed at ceiling. In a follow-up experiment, Kadyamusuma et al. (2011b) examined the perceptual abilities of Shona speaking LHDs and RHDs to discriminate pitch in Shona words (with lexical tone) and in their low-pass filtered analogues. Their results showed that in both tasks, the LHDs showed more impairment than the RHDs. This suggests that for the low-pass filtered speech task, although there was no segmental information present in the Shona words, the low-pass filtered stimuli still remained linguistic in nature, and hence, were processed like Shona words (Kadyamusuma et al., 2011b). Taken together, there is evidence for a bilateral processing of lexical tone in tonal languages, with the left hemisphere being dominant (Kadyamusuma et al., 2011b).

So far, all the studies on tonal processing in individuals with damaged and healthy brains have focused on lexical tone, leaving grammatical tone an untapped area of research. Thus, it is not known yet how grammatical tone is processed. Typologically, tonal languages in Africa are different from those spoken in Asia, in terms of tone inventories and rule systems (Gandour, 1998; 2006). This has made it insufficient to formulate theories which could be generalized to African tonal languages. For example, Akan has a grammatical function of tone which does not exist in neither Chinese nor Thai. Additionally, while lexical tone may require only a word level processing (i.e. differences in lexical meaning), grammatical tone may require processing beyond the word level (e.g. a temporal relation between an adverb and a verb, expressed through grammatical tone in Akan). Therefore, examining grammatical tone processing in individuals with brain damage will give more insights into the already existing theories about tone processing in tonal languages.

Therefore, in this study we investigate this issue using Akan, a Kwa language spoken in Ghana, which has grammatical tone.

2.1.2. Features of Akan

Akan is a tonal language with two basic tones: High tone and Low tone, which are pronounced on a relatively level pitch (Abakah, 2000; 2005; Dolphyne, 1988). The meaning of a sentence or a word in Akan is not only dependent on the vowels and the consonants that make up the words, but also on the pitch with which each syllable is produced (Dolphyne, 1988; Osam, 2003, 2008). Pitch in Akan can be used for both lexical (eg. *pàpá* – 'father', *pápá* – 'good', *pàpà* – 'fan') and grammatical functions (see Examples 1a-b). That is, unlike in other tonal languages (such as Chinese) where pitch is used only for contrasts of lexical meaning, in Akan, certain grammatical categories such as verb inflection (tense/aspect) can be distinguished by tone (Dolphyne, 1988). Below are examples of grammatical tone in Akan.

(1a)	*Papa no*	*twèrɛ́*	*lɛ́tɛ̀*
	man the	write-HAB	letter.
	'The man writes letter(s)'		

(1b)	*Papa no*	*twèrɛ́ɛ̀*	*lɛ́tɛ̀*
	man the	write:PAST	letter
	'The man wrote letter(s)'		

In Example 1a–b, the same verb "-twerɛ-" (meaning 'to write') is perceived as either present habitual as in (1a) or past tense as in (1b), depending on the tonal marking of the syllabic units of the verb. Whereas the tonal pattern on the disyllabic verb for the habitual aspect in (1a) is Low – High, the past has a Low-High-Low tonal pattern, with a prolonged vowel in the last syllable (1b). Thus, the difference between the habitual and the past is indicated solely by tone and duration.

2.1.3. The current study

The goal of this study was to address the mechanisms of grammatical tone perception by answering two primary research questions. The first question was: do individuals with LHD and those with RHD differ in their ability to perceive grammatical tone, as has been observed for lexical tone perception? Our prediction was that Akan speakers with LHD will show more impairment in grammatical tone perception than RHD speakers. This is because in grammatical tone, pitch signals grammatical processes, which in the previous literature have been found to be problematic for individuals with LHD (Tsiwah et al., 2020), whereas individuals with RHD generally are not expected to present with such problems with grammatical processing.

The second research question was: do individuals with LHD and RHD show different impairment patterns when pitch is used for linguistic functions (such as grammatical contrast) compared to when it is used for non-linguistic purposes (pure tone perception)? For the non-linguistic task, we predicted that the individuals with LHD should have fewer problems than the individuals with RHD. Further, individuals with LHD were predicted to perform better in non-linguistic tone perception than in grammatical tone perception, since the former does not involve linguistic operations. In contrast, the individuals with RHD were expected to show equal performance in grammatical tone and non-linguistic tone perception.

These predictions were based on the findings that the processing of pitch variations is right lateralized when it contains purely acoustic units (non-linguistic), but when tone is used for linguistic functions, processing is left lateralized (Whalen & Liberman, 1987; Liberman & Whalen, 2000). We addressed these questions by examining the perceptual discrimination abilities of native Akan speakers with LHD, RHD and without brain damage, in both a grammatical tone (linguistic) and a pure tone (non-linguistic) task. Here we focus on the Akan present habitual and the past which are solely distinguished by tonal height and duration (see Example 1a-b earlier).

2.2. METHODS

2.2.1. Participants

The present study included two clinical groups and ten non-brain damaged (NBD) participants. The clinical groups consisted of six individuals with LHD and agrammatic aphasia (see Tsiwah et al., 2020 for the diagnosis criteria) and six individuals with RHD and no aphasia. The individuals with LHD were four males and two females, with a mean age of 52 (range: 19 – 76, SD = 16.9) years, while the RHD group included 5 males and 1 female with a mean age of 53 (range: 34 – 67, SD = 13.3) years. The NBDs comprised five males and five females with a mean age of 51 (range: 35 – 71, SD = 11.5) years. The minimum number of years of formal education among all three groups was 9 years (range: 9 – 18). All participants spoke Akan as their native language, and had been using Akan as their primary language since birth.

The two clinical groups were recruited from the Speech and Language Therapy Centre, and the Physiotherapy Center at Korle Bu Teaching Hospital, Ghana. CT scans showed that all participants in these groups had suffered from a single stroke either in the left or right hemisphere. All participants were right- handed (with exception of one individual with RHD, who was ambidextrous). The time post-onset of stroke ranged from 3 to 36 months (see Appendix A for full demographic data). None had vision or hearing problems. The study received approval from the boards of the Research Ethical Review Committee (CETO) of the Faculties of Arts, Philosophy, and Theology and Religious Studies, University of Groningen, and the Korle Bu Teaching Hospital-Institutional Review Board (KBTH-IRB), Accra, Ghana. All participants gave their written informed consent.

2.2.2. Materials and Procedure

The materials and procedure used in Tsiwah et al.'s (2020) study were also used for the current study. For a more detailed description, see Tsiwah et al. (2020).

Non-linguistic tone perception task

The non-linguistic task comprised a Tonal Screening Test (TST: Kayser, 2011; Bruder et al., 2004; 2011; Wexler et al., 1998; Stevens et al., 2000), in which the members of a pair of non-linguistic tones must be judged to be either the same or different. The tones were made up of 300-ms sine waves with frequencies between 325Hz and 1994Hz. For example, tonal pairs with frequencies of 1328Hz – 1129Hz and 680Hz – 680Hz made up different and same tones, respectively. There was a total of 70 tonal pairs: 10 practice items, and 60 main trials (30 same, 30 different tones pairs).

Linguistic tone perception task

The comprehension subtest of the African version of the Test for Assessing Reference of Time (TART: Abuom & Bastiaanse, 2010) was adapted to Akan for the linguistic tone perception task.

A total of 16 transitive verbs (e.g. *to drink; to write*) were used in a spoken-sentence-to-picture-matching paradigm. Each of the 16 experimental verbs appeared twice; once in each time frame (past and present), making a total of 32 experimental trials. The order of the 32 trials was randomized. Each action was depicted by two pictures, one placed above the other (see Figure 2.1).

Fig 2.1. Example of the Linguistic task, with the target sentence 'the man ate the orange'. © University of Groningen.

Target pictures for the past time frames were contrasted by a picture with the same action in the present time and vice versa. An example of the items is given below.

(2)	*Experimenter:*	*Pàpá*	*nó*	*hwànéè*	*ànkàá*	*nó.*
	Man	the	peel:PAST	orange	the	
	The man peeled the orange.					

A pair of pictures was presented to the participants and the sentence was read aloud by the experimenter. The participants had to point to the picture that matched the spoken sentence. A response was correct when the participants pointed to the picture that matched the time frame encoded in the sentence that was read out loud.

2.2.3. Data Analysis

To test for differences between the three groups across tasks, generalized linear mixed-effects modelling (GLMM) was performed using the *glmer* function of the lme4 package (Bates et al., 2013) and the *glht* function of the *multcomp* package (Hothorn et al., 2013) in R (R Core Team, 2013). The dependent variable (Score) in the model was accuracy (1 = correct, 0 = incorrect) with random effects factors for items and participants. The model included the fixed effects Group (LHD, RHD and NBDs) and Task (LT and Non-LT), with and without the interactions between these variables. To account for variability across Group and Items, the model also included random slopes for Group per Item. The best model (see Table 2.2 for the complete output), which included an interaction between Group and Task, was chosen based on the AIC and the log likelihood ratio tests of the full model with the effect (interaction) in question against the model without the effect (interaction)in question (with significance at $p < 0.001$).

2.3. RESULTS

In Figure 2.2 and Table 2.1, the mean percentage of correct responses on the two tasks are given for the LHD, RHD, and the NBD groups (see Appendix 2-2 for the output of the full model). There was a significant interaction between Group and Task (model with interaction: AIC = 1278.1; model without interaction: AIC = 1289.7; significance at $p < 0.001$).

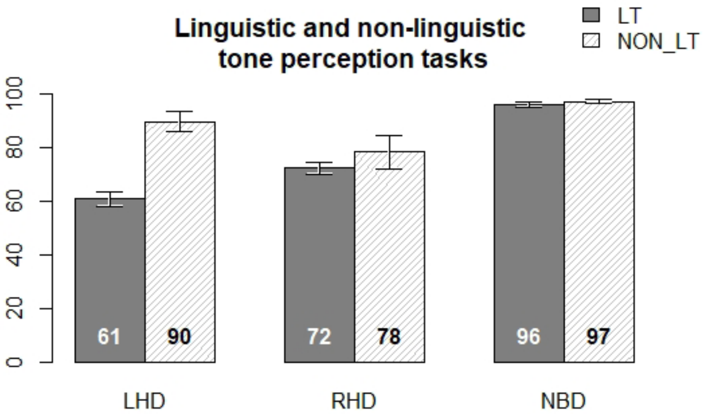

Figure 2.2. Percent mean accuracy scores per task (LT = Linguistic task; NON_LT = Non-linguistic task) per group of participants, including standard error bars.

Table 2.1. Percentage of accuracy scores on non-/linguistic tone discrimination task

Groups	Grammatical tone	Pure Tone
LHD1	56*	98
LHD2	71*	90*
LHD3	59*	92*
LHD4	53*	72*
LHD5	65*	90*
LHD6	59*	96
Mean (SD)	**61 (6.77)**	**90 (9.51)**
RHD1	78*	75*
RHD2	69*	80*
RHD3	66*	71*
RHD4	69*	53*
RHD5	75*	96
RHD6	78*	93*
Mean (SD)	72 (5.38)	78 (15.77)
NBD (Mean) (SD) (range)	**96 (2.9)** **88-100**	**97 (1.96)** **95 – 100**

Note: LHD = left hemisphere damage; RHD = right hemisphere damage; NBD = non-brain damage; SD = standard deviation;
* outside the range of NBD

The post hoc analysis showed that overall, the accuracy of the NBDs was significantly higher than the accuracy of the individuals with LHD and the RHD on the linguistic (LHD: $\beta = 7.10$, SE = 1.47, $z = 4.84$, $p < 0.001$; vs RHD: $\beta = 5.13$, SE = 1.33, $z = 3.85$, $p = 0.001$) and the non-linguistic (LHD: $\beta = 4.80$, SE = 1.46, $z = 3.28$, $p = 0.009$; vs RHD: $\beta = 6.08$, SE = 1.44, $z = 4.22$, $p < 0.001$) tasks. Further, there was no significant difference between the individuals with RHD and LHD on their performance on the linguistic task ($\beta = 0.43$, SE = 0.45, $z = 0.96$, $p = 0.911$). However, the non-linguistic task showed a significant difference in performance between the RHD and LHD groups ($\beta = 1.28$, SE = 0.41, $z = 3.09$, $p = 0.018$), with the former performing worse than the latter. Across task comparison showed that the individuals with LHD performed significantly better on the non-linguistic task than on the linguistic task ($\beta = 2.31$, SE = 0.43, $z = 5.42$, $p < 0.001$). The individuals with RHD showed no difference in performance on the linguistic and the non-linguistic tasks ($\beta = 0.59$, SE = 0.27, $z = 2.16$, $p = 0.210$).

2.4. DISCUSSION

The first goal of the current study was to investigate whether Akan individuals with LHD and those with RHD show impairments in their abilities to perceive grammatical tone, to determine the extent to which any impairment in grammatical tone perception showed the same pattern as the deficits that have been found for lexical tone in other tonal languages. The second goal was to examine whether linguistic (grammatical) and non-linguistic (pure pitch) perception differed for individuals with LHD and the RHD. Our findings will be discussed in the light of the two dominant models that have been proposed to account for the hemispheric asymmetry of human pitch perception, namely, *the function-dependent brain asymmetry* and the *acoustic-dependent brain asymmetry* models.

2.4.1. Grammatical tone processing

With respect to the first research question, we found that both the LHD and the RHD speakers of Akan had difficulties in perceiving grammatical tone as compared to the non-brain damaged individuals. That is, an impairment in either the left or the right hemisphere resulted in a reduced ability to perceive grammatical tone. Comparatively, this is consistent with brain lesion data for lexical tone perception in other tonal languages: both individuals with left and right hemisphere brain damage show impairments in lexical tone perception (Norwegian: Moen & Sundet 1996; Thai: Gandour & Dardarananda, 1983; Gandour et al., 1992; Shona: Kadyamusuma et al., 2011a). Surprisingly, the right hemisphere damaged individuals did not perform significantly better (or worse) than the individuals with left hemisphere damage in our study. That is, problems with grammatical tone perception were equally pronounced in individuals with left and right hemisphere damage, and this is not in line with the findings of previous studies on lexical tone. However, with a small sample size, caution must be applied, as our results might not entirely be representative of how these two groups perceive grammatical tone. It is important to note that the mean accuracy of the individuals with LHD on the linguistic task was considerably lower than that of the RHD group, although the statistical model did not show that this difference was significant. Additionally, the individual scores showed that all individuals with RHD were better than the LHD individuals. Therefore, the absence of a statistical significance might be due to the small sample size of our data. We conclude that, this consistent pattern of impairment that has been observed in lexical tone perception in individuals with LHD and RHD can be extended to grammatical tone perception, and that a bigger sample size is needed to be able to establish a well-defined asymmetry between these two groups.

2.4.2. Hemispheric lateralization of linguistic and non-linguistic tone processing

In the light of the two prominent models that account for the hemispheric lateralization of tone, the observed pattern of impairment in grammatical tone perception in the current study lends support to the *function-dependent brain asymmetry* model (Van Lancker 1980). According to this model, lateralization is dependent on the function of pitch. That is, on one hand, when pitch variations are processed primarily as acoustic (non-linguistic) units, their processing is lateralized to the right. However, when pitch is used to serve linguistic purposes, the processing is left lateralized (Whalen & Liberman, 1987; Liberman & Whalen, 2000). Function-dependent brain asymmetry predicts that damage to the left hemisphere results in worse performance in lexical/grammatical tone perception than damage to the right hemisphere. This asymmetry did not prove to be significant in the current study, although there was an overall trend. However, the fact that the individuals with RHD in turn performed worse than the individuals with no brain damage is inconsistent with the assumptions of this model. One potential explanation for the reduced performance of the individuals with RHD could be attributed attention and short-term memory deficits, the commonly reported deficits for individuals with RHD (Blake, et al., 2002; Tompkins 1985; 2012). Since discrimination tasks require the involvement of such cognitive control abilities (Miller & Cohen, 2001), it is possible that the subdued performance of the RHD individuals in the grammatical tone task is as a result of an increased cognitive load. Another possible explanation can be attributed to the inability of the RHD individuals to perceive tone in general, and, thus, leading to the failure to perceive linguistically relevant (grammatical) tone (more on this later).

Turning now to the question of whether Akan individuals with LHD and RHD show different and/or similar impairment patterns when perceiving linguistic and non-linguistic tones, our predictions were threefold. The first prediction was that individuals with RHD would show more impairments in non-linguistic tone perception than the individuals with LHD. Our results indicated that this was the case: non-linguistic tone perception was relatively better in the individuals with LHD, than the individuals with

RHD. However, one RHD patient (RHD5) who was ambidextrous, performed within the range of the individuals with no brain damage. It is important, however, to note that the spontaneous speech of RHD5 showed that there was no aphasia present. Overall, this pattern of results observed for the individuals with RHD and LHD is in-line with the assumptions of the function-dependent brain asymmetry model. Thus, the hemispheric lateralization of pitch processing is dependent on the function pitch serves: non-linguistic and linguistic functions tend to be right and left lateralized, respectively (Whalen & Liberman, 1987; Liberman & Whalen, 2000). Therefore, damage to the right (rather than the left) hemisphere is more likely to result in difficulties in perceiving pure tone variations. Nevertheless, this is contrary to the findings of Kadyamusuma et al. (2011b) who showed that Shona speaking individuals with LHD were still more impaired than the RHD individuals in the lowpass filtered (supposedly non-linguistic) task. An explanation for this discrepancy can be attributed to the differences in the nature of non-linguistic stimuli used in the current study and that of Kadyamusuma and colleagues (2011b). While the current study used pure tone stimuli, Kadyamusuma and colleagues (2011b) used low-pass filtered minimal pairs homologous to the bisyllabic Shona words, which may have still remained linguistic in nature, and hence, were processed like the Shona words rather than non-linguistic units.

The second prediction was that the LHD group would perform better on pure non-linguistic rather than linguistic tones. As shown by our results, all individuals with LHD showed a better performance in pure (non-linguistic) tone perception than when pitch was used for grammatical (linguistic) purposes. Again, this is consistent with the assumptions of the *function-dependent brain asymmetry* model. That is, since pure tone variation signals no grammatical processing, individuals with LHD should show fewer problems in perceiving them than the grammatical tones.

Thirdly, regarding the ability of the RHD group in grammatical tone and non-linguistic tone perception, we predicted that for this group, there should be no difference in performance whether pitch is processed as speech or as non-speech. Our results showed that this is the case. The RHD group showed no difference in their ability to perceive the linguistic and the non-linguistic tones. Meaning, for this group of individuals, both linguistic and non-linguistic tone perception is problematic. This pattern is consistent with the *acoustic-dependent brain asymmetry* model (rather than the *function-dependent brain asymmetry* model), which proposes that pitch patterns are processed on the basis of their acoustic structures, regardless of their functions, and are, therefore, processed only by the right hemisphere (Van Lancker & Sidtis, 1992; Sidtis & Van Lancker-Sidtis, 2003; Zatorre & Belin, 2001). Hence, damage to the right hemisphere should result in difficulties in both linguistic and non-linguistic tone perception.

Thus far, our results have demonstrated consistent involvement of the left hemisphere in grammatical (linguistic) tone perception, whereas this hemisphere is relatively less involved in non-linguistic tone perception, denoting a left lateralization for linguistically-relevant prosodic cues, as predicted by the *function-dependent brain asymmetry* model. However, the pattern of impairment for the individuals with RHD suggests an involvement of the right hemisphere in both grammatical tone and non-linguistic tone perception, as predicted by the *acoustic-dependent brain asymmetry* model. What is clear from the current study is that a strict dichotomy in hemispheric lateralization for either linguistic or non-linguistic tone perception is not well-founded. In fact, both the LHD and the RHD groups show reduced performance in tone perception, as compared to the non-brain damaged group, suggesting that to some extent, both hemispheres are involved in (lexical or grammatical) tone perception. It is clear that claiming one or the other as the sole explanatory model on the basis of the current data is impossible. Consequently, as proposed in a review study by Zattore and Gandour (2009), these two models should not be treated as mutually exclusive, and thus, aspects of each model would have to be integrated into a more comprehensive model of bilateral hemispheric involvement in tone processing.

2.4.3. Conclusions and recommendations for future research

In summary, we have shown that Akan individuals with either LHD and RHD show impairment in grammatical tone perception, just as has been observed for lexical tone in languages. Nonetheless, the asymmetry between these two groups was no demonstrated in our study. Based on the underlying assumptions of both the *function-dependent brain asymmetry* and the *acoustic-dependent brain asymmetry* models, hemispheric lateralization should diverge when native speakers of tonal languages process either linguistically or non-linguistically-relevant prosodic cues. However, the findings of the current study show that an explanation of these results with one simple dichotomy is inadequate. Therefore, these two models should be perceived as complimentary rather than mutually exclusive.

A possible area of future research would be to investigate the *production* of grammatical tone in similar clinical groups. Such a study should adopt a well-defined acoustic and phonetic analysis to investigate the extent to which phonetic and acoustic features may differ for individuals with LHD and RHD. Also, since linguistic tone perception varies depending both on the site and severity of the damage (Gandour et al., 1992), future studies should consider examining these effects in relation to both linguistic and non-linguistic tone processing.

CHAPTER 3

Processing of time reference in agrammatic speakers of Akan: a language with grammatical tone[1]

ABSTRACT

Background: Languages of the world have several ways of expressing time reference. Many languages such as those in the Indo-European group express time reference through tense. Languages such as Chinese and Standard Indonesian express time reference through aspectual adverbs, while Akan does so through grammatical tone. Previous studies have found that time reference is selectively impaired, with reference to the past being more impaired than reference to the non-past (see Bastiaanse, 2013, for overview). The PAst DIscourse LInking Hypothesis (PADILIH: Bastiaanse et al., 2011) posits that past time reference is difficult because it requires discourse linking.
Aims: The goal of this study was first to examine whether past time reference is impaired also in languages that do not use grammatical affixes but rather tone, to make time reference. Second, this study aims to decouple the effect of tone from the effect of temporal reference on Akan verbs.
Method and Procedures: Ten Akan agrammatic speakers and ten non-brain-damaged speakers (NBDs) participated in this study. An Akan adapted version of the Test for Assessing Reference of Time (African TART: Abuom and Bastiaanse, 2010), for both production and comprehension was used. The TART focuses on the future, present (habitual) and the past time frames. Additionally, five of the agrammatic speakers performed two tonal discrimination tasks: a non-linguistic and a linguistic (lexical) one.
Outcomes and Results: While the NBDs scored at ceiling, the agrammatic speakers made errors, and these affected past more than present and the future time references, in both comprehension and production tasks. However, the comprehension data showed a dissociation between the present habitual and the future. The substitution error analysis revealed a preference for the present. The five agrammatic speakers showed an intact performance on non-linguistic tonal discrimination task.
Conclusion: The conclusion is that regardless of how time reference is expressed, whether through inflectional morphology or grammatical tone, reference to the past is problematic for individuals with agrammatic aphasia. The fact that the agrammatic speakers could perceive the non-linguistic tonal differences demonstrates that it is not tone in general that is disrupted, but rather time reference, particularly reference to the past, as predicted by the PADILIH.

Keywords: Grammatical tone, agrammatic aphasia, tense, time reference, Akan

1 This chapter has been adapted from: Tsiwah, F., Lartey, N., Amponsah, C., Martínez-Ferreiro, S. & Bastiaanse, R. (2020). Processing of time reference in agrammatic speakers of Akan: A language with grammatical tone. Aphasiology. Online publication.

3.1. INTRODUCTION

Languages around the world have several ways of expressing time reference. Many languages such as those in the Indo-European group express time reference through tense (Reichenbach, 1947; Comrie, 1976; and many others). Many Asian languages, such as Chinese and Standard Indonesian, express time reference through aspectual adverbs (Smith and Erbaugh, 2005; Grangé, 2003;2006), while Akan, a language in the Niger-Congo family, does so through grammatical tone (Dolphyne, 1988). Recent studies have demonstrated that time reference, particularly reference to the past is impaired in individuals with agrammatic aphasia, while reference to the non-past (present and future time reference) are relatively spared (Abuom and Bastiaanse, 2012; Bastiaanse, 2008, 2013; Bastiaanse et al., 2011; Bos and Bastiaanse, 2014; Dragoy and Bastiaanse, 2013; Martínez-Ferreiro and Bastiaanse, 2013). The PAst DIscourse LInking Hypothesis (PADILIH: Bastiaanse et al., 2011) posits that past time reference is difficult because it requires discourse linking, whereas for reference to the non-past (present and future) no discourse-linking is needed (see next section for further details about the PADILIH). The issue of time reference has been extensively studied in languages that use inflectional verb morphology[2] for time reference, but there are little data on languages that do not. Thus, it remains unclear whether the impairment in past reference reflects a combined selective deficit in time reference and grammatical morphology or a selective deficit in time reference only.

The current study investigates the ability of individuals with agrammatic aphasia to refer to different time frames and to process/comprehend time reference in Akan, a language that expresses time reference by grammatical tone, rather than tense. The question is whether time reference difficulties, particularly reference to the past in agrammatism are restricted only to languages that use verb morphology (such as tense), or whether the impairment can be extended to tonal languages that use grammatical tone to express time reference, such as Akan.

3.1.1. Tense, Aspect, Time reference and the PADILIH

Comrie (1985) defines Tense as the "grammaticalised expression of location in time". That is, tense is a grammatical category that conveys information about the time in which an event takes place, usually relating the event time to the speaking time. While Tense is a grammatical category, Time Reference is a semantic category that is closely related to Tense. Similarly to tense, Aspect is a semantic category, in many languages grammaticalized

2 We realize that the term 'inflectional morphology' may be confusing, because changes in tone to denote tense are, by some linguists, considered to be inflectional as well (see, e.g., Palancar and Léonard, 2016, who distinguish lexical tone and inflectional tone). Here, we mean by 'inflectional morphology' and 'inflectional morphemes' only those bound morphemes that are added to the verb stem, such as English *-s, -ed* and *-ing*. The aspectual adverbs as used in Chinese and Standard Indonesian are referred to as 'free grammatical morphemes'.

and encoded in the verb, that describes the internal temporal constituency of an event by indicating whether it is completed (perfective aspect), ongoing (imperfective aspect) or repetitive (imperfective aspect) (Comrie, 1976). Many studies on aphasia have shown that the processing of tense, which indicate the time reference of an event, are problematic. (Bastiaanse, 2008; Burchert, Swoboda-Moll, and De Bleser, 2005; Friedmann and Grodzinsky, 1997; Gavarró and Martínez-Ferreiro, 2007; Nanousi, Masterson, Druks, and Atkinson, 2006; Wenzlaff and Clahsen, 2004, 2005). Further, recent studies have demonstrated that not all time frames are equally impaired in agrammatism, and that reference to the past is more susceptible to being impaired than reference to the present and the future. Interestingly, it is not just past tense that is difficult, but rather reference to the past. In Dutch (and German), reference to the past can be done both by past tense (in combination with perfect or imperfect aspect) and by present perfect. Here, perfect aspect denotes that the event took place in the past, even though the finite verb (auxiliary) is in present tense. Production of the present perfect is impaired in Dutch agrammatic speakers (Bos and Bastiaanse, 2014). Apparently, an event that has been completed is difficult to express through verb inflection: perfect is impaired in Dutch agrammatic speakers, even though the finite verb is in present tense.

According to Avrutin (2000, 2006), the processing of tense requires access to 'discourse syntax', where a link has to be made between the sentence and the discourse, unlike subject-verb agreement which requires only an intra-sentential linkage (resolved within 'narrow syntax') to process. Avrutin claims that problems with tense should be more often observed than problems with subject-verb agreement in the speech of patients with Broca's aphasia because discourse linking (extra sentential processing) requires more processing resources than narrow syntax (intra-sentential processing). Zagona (2003) makes it even more specific, and suggests that it is not tense per se that is discourse linked but verb tense that makes reference to the past. According to Zagona (2003), present verb tense is bound locally (intra-sententially) because the time of the event and speech time coincide, and thus, present tense is not discourse linked. Future time reference is categorized as a subclass of present tense, hence it is not discourse linked either (Zagona, 2013). Therefore, only past tense needs to be discourse linked.

Building on the ideas of Zagona (2003) and Avrutin (2000; 2006), Bastiaanse et al., (2011) and Bastiaanse (2013) formulated the PADILIH, which claims that past time reference, whether expressed through tense and/or aspectual verb inflection, is selectively impaired because it has to be linked to the discourse. That is, reference to the past through free and bound grammatical morphemes, including periphrastic verb forms denoting perfect aspect that refer to a completed action (in Dutch *heeft gelezen:* lit. 'has walked') is impaired. According to the PADILIH, when referring to the past, the time of speaking does not coincide with the event time, hence, a link between these two different time points has to be established. However, reference to the present requires that the time of speaking coincides with the time of the event, and hence, no discourse linking is required.

In reference to the future, although the time of speaking and event time do not coincide, there is no discourse linking since the event has not yet taken place. Additionally, future reference is not bound within the sentence nor to the discourse. Bastiaanse (2013) follows Zagona (2013) and suggests that both the present and the future time reference could be paired as 'non-past', and thus, are assumed to be less costly.

The PADILIH accounts for the selective impairment of past time reference which has been found in many studies on aphasia across different clinical populations and languages (English and Turkish: Bastiaanse et al., 2011; Russian: Dragoy and Bastiaanse, 2013; Dutch: Bos and Bastiaanse, 2014, Bastiaanse, 2008; Spanish: Martínez-Ferreiro and Bastiaanse, 2013; Korean: Lee, Kwon, Na, Bastiaanse, and Thompson, 2013). The predictions of the PADILIH are supported not only by evidence from monolingual aphasia but also by production and comprehension data from bilingual agrammatic aphasia. For instance, whenever the bilingual agrammatic speakers reported by Abuom and Bastiaanse (2013) and Abuom, Obler and Bastiaanse (2011) made time reference errors, past reference was most affected, whereas present and future reference was relatively intact. Importantly, this pattern emerged in both languages of the agrammatic participants, despite the fact that they vastly differed morphologically. Recently, some studies have shown that the selective impairment of past time reference, as claimed by the PADILIH, is not restricted to agrammatic aphasia, but also extends to fluent aphasias (Dragoy and Bastiaanse, 2013; Bos and Bastiaanse, 2014). Interestingly, the PADILIH also accounts for the selective impairment in the use of past and non-past in patients with Alzheimer's disease (AD) and semantic dementia (SD): Irish et al. (2016) examined the use of past and present tenses in autobiographical narratives in patients with AD and SD, and found that verbs referring to the past were significantly compromised in both groups, as compared to the healthy speakers. Further, the cross-linguistic (Greek and Italian) individual data from speakers with AD showed a worse performance on past reference than on future reference (Fyndanis et al., 2018b), which is consistent with the PADILIH.

However, some studies have demonstrated conflicting results on the present and the future time reference. Martínez-Ferreiro and Bastiaanse (2013) found that Spanish and Catalan individuals with non-fluent aphasia show a dissociation between the present and the future, with the present being better preserved, in comprehension. Nonetheless such difference was not replicated in production. The asymmetry between the future and the present habitual has also been found in Greek-speaking agrammatic individuals, who showed a significantly better performance in simple present than simple future in Greek (Nanousi et al.,2006). Faroqi-Shah and Friedman (2015) and Fyndanis et al. (2018a) also challenge the validity of the PADILIH. Fyndanis et al. (2018a) reported that, at the group level, Greek-speaking and Italian-speaking individuals with agrammatic aphasia were equally impaired in past and future reference, whereas Faroqi-Shah and Friedman (2015) did not find any consistent differences between present, past and future tense.

The PADILIH has also been tested in languages that do not use verb inflection but rather free-standing aspectual adverbs for time reference, such as Chinese and Standard Indonesian (Chinese: Bastiaanse et al., 2011; Standard Indonesian: Anjarningsih and Bastiaanse 2011). In these languages, the aspectual adverbs are optional, and are only used when the time frame of the event is not clear from the context. Therefore whether an event is completed or not depends on the internal temporal constituency of the event; and this piece of information is not discourse-linked, because aspectual information is non-deictic (Comrie, 1976). This is supported by the data: both in Chinese and in Standard Indonesian, reference to past, present and future is equally impaired in agrammatic production (Bastiaanse, 2013).

In this section, it has been explained that time reference is problematic when discourse linking is required. Nonetheless, depending on the structure of a language, and the linguistic means by which time reference is expressed, different time frames may be affected. The section that follows describes the structure of Akan, particularly grammatical tone.

3.1.2. Linguistic background of Akan

Akan is a language spoken in sub-Saharan Africa, particularly Ghana, as well as in the eastern part of Cote d'Ivoire. Akan belongs to the Kwa group of the Niger-Congo language family. There are three main dialects of Akan namely: Asante Twi, Akwuapim Twi and Fante. All the three dialects are mutually intelligible. The Akan dialect under study is the Asante Twi, the most widely spoken dialect. About 48% of Ghana's population of 24 million are native speakers of Akan (Ghana Statistical Service 2010). Nonetheless, an overall estimate of 80% of Ghanaians speak Akan as either the first or second language. A form of Akan is also spoken in some parts of the Caribbean, notably Suriname and Jamaica, as a result of the trans-Atlantic trade. In Ghana, the educational policy requires that a child can use his/her native language as the medium of instruction and communication until Grade 3 (Mfum-Mensah, 2005). Although English is the official language in Ghana, Akan is the most dominant language used in the media, trade, religion, political campaigns and day-to-day interaction among people. Linguistically, Akan has some distinctive features such as tone, vowel harmony, nasalization, and the phenomenon of serialization. The base word order of Akan is Subject Verb Object (SVO).

Akan is a tonal language. This entails that the meaning of a sentence in Akan depends not only on the vowels and the consonants that make up the words, but also on the relative pitch with which each syllable of the sentence is produced (Dolphyne, 1988; Osam, 2003, 2008). Akan has two basic tones: High tone (H) and Low tone (L), and they are pronounced on a relatively level pitch (Abakah, 2000; 2005b; Dolphyne, 1988). In Akan, tone has both lexical and grammatical functions.

Lexical tone:

(1a) *Pàpá* 'father'

(1b) *Pàpà* 'fan'

(1c) *Pápá* 'good'

Grammatical tone:

(2a) *Peter* *gyìná* *hɔ*
Peter stand-HAB there.
Peter stands there

(2b) *Peter* *gyìn*áà *hɔ*
Peter stand-PAST there.
Peter stood there.

(2c) *Peter* *bégyíná* *hɔ*
Peter FUT-stand there.
Peter stands there

In the Akan examples from (1a) – (1c), the meaning of the word '*papa*' changes depending on the tonal pattern of the vowels. Similarly, in the grammatical tone examples (2a) – (2c), the same verb "-gyina-" (meaning 'stand') is perceived as either habitual aspect as in (2a) or past tense in (2b) depending on the tone on the syllabic units of the verb. That is, the difference between the habitual and the past is indicated solely by tone and duration. Whereas the tonal pattern on the disyllabic verb for the habitual aspect in (2a) is Low – High, the past has a Low-High- Low tonal pattern, with a prolonged vowel in the last syllable, as in (2b). In the case of mono-syllabic verbs, the tone of the habitual aspect is always High. In (2c), which is the Akan future, the verb has to be prefixed by the morpheme *bɛ́-/bé* with a high tone. The future verb form is marked by a High-High-High tone pattern in (2c).

The Akan past and the habitual time frames are semantically distinctive. According to Boadi (2008), it is inappropriate to refer to the marker (tone) of the Akan habitual as present tense (since it does not locate events in time) although it is used to express present time and/or any indefinite time. Nonetheless, Boadi (2008) refers to the habitual as the 'Present habitual' since it semantically connotes the idea of present time rather than past. In sum, the Akan habitual always expresses a non-past time. Therefore, we refer to the Akan habitual aspect as 'present habitual'.

3.1.3. Tone processing in aphasia

Although there are about 1000 estimated tonal languages in Africa (Fromkin and Rodman, 1993), studies on tone processing in aphasia have predominantly focused on Thai, Chinese and Norwegian (Gandour, Ponglorpisit, and Dardarananda, 1992; Liang and Van

Heuven, 2004; Moen, 2009; Van Lancker, 1980; Yiu and Fok, 1995). Studies on non-brain-damaged individuals have shown that acoustic processing, such as processing of pitch, predominantly involves the right hemisphere whereas the processing of phonological information, including linguistic tone, is more left lateralized (Wong 2002; Zatorre, Belin, Penhune, 2002; Friederici and Alter, 2004). Most of these studies, if not all, have focused on perception and/or production of lexical tone, and have demonstrated that tone language speakers with aphasia show substantial impairment in lexical tone processing (Gandour, Petty, and Dardarananda, 1988; Kadyamusuma, de Bleser, and Mayer, 2011).

Yiu and Fok (1995) demonstrated that Cantonese tone processing is disrupted in individuals with aphasia while it is intact in dysarthric patients, hence the tone processing deficit could be attributed to the lesion sites (especially in the left hemisphere) that result in aphasia. They also reported that Cantonese aphasic speakers produce more tonal errors than consonant or vowel errors. This is consistent with the findings of Liang and Van Heuven (2004), who examined the speech of a female Mandarin-speaking individual with Broca's aphasia and found that her production of lexical tones was more disrupted than production of vowels. Based on their findings, Liang and van Heuven (2004) suggested a separate function and localization for segmental and tonal aspects of lexical entries in tonal languages. Additionally, Gandour, Ponglorpisit, and Dardarananda, (1992) reported that Thai speakers with nonfluent aphasia show a higher error rate in both perception and production of lexical tone in Thai. Kadyamusuma, de Bleser, and Mayer (2011)a Bantu language. Van Lancker (1980 investigated the ability of aphasic individuals with left hemisphere damage to identify lexical tone in Shona, a Bantu language spoken in Zimbabwe. In Kadyamusuma et al.'s (2011) study, the Shona-speaking participants with aphasia were found to be impaired in lexical tone perception. The disruptions shown in lexical tone processing in Shona, an African language, are consistent with previous findings in other tone languages such as Chinese and Thai (Gandour and Dardarananda, 1984; Yiu and Fok, 1995).

Furthermore, Gandour et al., (1992a,b) demonstrated that tonal duration is relatively intact in Thai nonfluent aphasia. Thai tones vary in terms of duration, with the falling tone and the mid tone being the shortest and the longest tones, respectively. Gandour and colleagues found that Thai speakers with nonfluent aphasia have a preserved ability to control relative differences in tone duration associated with the Thai phonological contrast in vowel length (Gandour et al., 1992a,b; one transcortical motor, one global, one left subcortical aphasic, one language-delayed adult, and five normals. The five Thai tones (mid, low, falling, high, rising Gandour and Dardarananda, 1984).

In summary, there is cross linguistic evidence that patients with left hemisphere brain damage, particularly patients with nonfluent aphasia in Chinese (Yiu and Fok, 1995), Thai (Gandour et al., 1992a,b)one transcortical motor, one global, one left subcortical aphasic, one language-delayed adult, and five normals. The five Thai tones (mid, low, falling, high, rising, and Shona (Kadyamusuma, De Bleser and Mayer 2011), show a disruption in perception and production of lexical tone, with tonal duration being relatively intact. However, all the studies on tone processing in aphasia have explored lexical tone, leaving grammatical tone an untapped research area.

3.1.4. Goals of the present study

This study had two goals. The first goal was to find out whether the observed differences in past versus non-past (present and future) time reference are restricted to languages with morphological verb inflections, or whether they are also manifest in languages that express time reference through grammatical tone. The distinctive realization of the Akan present habitual aspect and the simple past, that are only different in tone and vowel duration, makes it a very suitable language to address this question. According to the predictions of the PADILIH, Akan speakers with agrammatic aphasia should have difficulty with reference to the past, although there is no verb inflection, since the deficit is claimed to affect discourse linking and not tense marking.

The second goal of this study was to investigate whether the presence of tense morphology (coupled with tone) makes the Akan future verb form more difficult than the present habitual verb form, which is marked solely by tone. According to Zagona (2013), future time reference is categorized as a subclass of present tense, hence not discourse linked. Therefore, the PADILIH predicts that both the future and the present time frames should be relatively spared (Bastiaanse, 2013). If the involvement of verb morphology negatively impacts the performance of individuals with agrammatic aphasia on tasks tapping into time reference, then Akan future time reference should be more difficult in both comprehension and production than reference to the present, which does not require inflectional morphology.

To address these goals, the current study used the Akan version of the Test for Assessing Reference of Time (TART: Bastiaanse et al., 2008; African TART: Abuom and Bastiaanse, 2010).

3.2. MATERIALS AND METHOD

3.2.1. Participants

The current study involved two participant groups: Ten individuals with agrammatic aphasia, and ten non-brain damaged (NBD) participants. The aphasia group consisted of seven males and three females, with a mean age of 53.9 (range: 19 – 76, SD = 16.9) years, while the NBD group consisted of 5 males and 5 females with a mean age of 51 (range: 35 – 71, SD = 11.5) years. Each participant in either of the groups had had at least 9 years of education formal education (Aphasia group: range = 10-16 years, mean = 13.3, sd = 2.49; NBD: range = 9-16 years, mean = 13.1, sd = 3.25). A two sample t-test showed no significant difference in years of formal education between the two groups (t=0.1544, *df*=16.89, *p*=0.88). All participants spoke Akan as their native language, and had been using Akan as their primary language since birth. All agrammatic speakers were recruited from the Speech and Language Therapy Centre, as well as the Physiotherapy Center, Korle Bu Teaching Hospital, Ghana. The presence of aphasia was established by a consensus between a Speech and Language Therapist and a neurolinguist.

All agrammatic speakers were right-handed premorbidly and reported having no history of neurological diseases or developmental speech and/or language disorders. No vision or hearing problems were present in any of the patients. Data from computerized tomographic (CT) scans showed that all patients had suffered from a single stroke in the left hemisphere. The time post onset of stroke ranged from 7 to 36 months (see Appendix 2-1 for all demographic data). The study was approved by the boards of the Research Ethical Review Committee (CETO) of the Faculties of Arts, Philosophy, and Theology and Religious Studies, University of Groningen, and the Korle Bu Teaching Hospital-Institutional Review Board (KBTH-IRB), Accra, Ghana. All participants gave their written informed consent.

Since there are no standardized tests for diagnosing aphasia syndromes in Ghana, the presence of agrammatic aphasia was diagnosed on the basis of the analysis of spontaneous speech samples, following the methods of Bastiaanse and Jonkers (1998). Spontaneous speech sample was elicited by questions on the history of stroke, how the participant spend their day and about their previous work. The speech sample from each participant was analyzed, and all agrammatic speakers showed reduced speech rate, Mean Length of Utterance (MLU) and produced more grammatical errors as compared to the NBDs (see Appendix 2-2 for the results of the spontaneous speech analysis). An Akan adapted version of the auditory word comprehension (nouns, verbs, letters and numbers) subtest of the *Boston Diagnostic Aphasia Examination* (BDAE: Goodglass and Kaplan, 1972) was also administered to test the agrammatic speakers' auditory single word comprehension abilities. The agrammatic speakers' scores on the BDAE are reported in Appendix 2-2. The word 'hammock' in the nouns subtest was not included in the Akan adapted version because it is not culturally appropriate for usage in Akan. All speakers with agrammatic aphasia showed a good single word comprehension and nonfluent speech.

3.2.2. Materials and Procedure

Pretests for tone discrimination abilities

Because grammatical tone perception is crucial in distinguishing between Akan past and present habitual, five[3] of the agrammatic speakers performed a Tonal Screening Test (TST: Kayser, 2011; Bruder et al., 2004; 2011; Wexler et al., 1998; Stevens et al., 2000), in which a pair of non-linguistic tones is judged to be either the same or different. The tones were

3 Patients were tested at different times, and the first five patients were tested at a time the Tonal Screening Test was not available yet.

made up of 300-ms sine waves with frequencies between 325 and 1994 Hz. There was 100 ms silence between each tonal pair. The TST had 70 tonal pairs in total: 10 practice items, and 60 main trials. The test included a 30 second break after every 20 trials. The purpose of this task was to ensure that the patients' ability to perceive non-linguistic tone was intact. Therefore, any errors (if any) made on the linguistic tone task(s) could not be attributed to a deficit in tone perception in general.

A second pretest was developed, similar to the first one, to assess the ability of the agrammatic speakers to perceive tonal and minimal phonemic differences. The test had a total of 30 minimal pairs consisting of 10 minimal pairs distinguished by lexical tone; 10 minimal pairs distinguished by phonemes; and 10 minimal pairs with neither phonemic nor tonal differences (sameness condition). The participants were asked to judge whether the pair of words they heard were different or the same, by pointing to a red card and green card, respectively. There was a break halfway through the task. Only five agrammatic speakers performed this task. Examples of lexical tone minimal pairs and phonemic minimal pairs are given in (3a) and (3b), respectively.

Lexical tone minimal pair			Phonemic minimal pairs		
(3a)	*pómà*	'to hit'	(3b)	*páḿ*	'to sew'
	pòmá	'walking stick'		*táḿ*	'to take'

The number of correctly answered trials were counted separately for each of the two tonal tests.

Test for Assessing Reference of Time (TART)

The African version of the Test for Assessing Reference of Time (TART: Abuom and Bastiaanse, 2010) was adapted to Akan for this study. The African TART has both a comprehension and a production subtest. All participants of the current study completed both tasks with the exception of three speakers with agrammatic aphasia (P3, P9 and P10) who withdrew from the production task.

Comprehension TART

For the comprehension subtest, a spoken-sentence to picture matching paradigm was developed. A total of 18 transitive verbs (e.g.'to pour') were used, out of which 16 and 2 verbs were used to create the experimental and practice items, respectively. Each of the 16 experimental verbs appeared three times; once in each time frame, and thus making a total of 48 experimental items. The test began with 6 practice items that consisted of 2 verbs, with each verb inflected for the present habitual, the past and the future to capture all three time frames. The order of the 48 items was randomized. Each action was depicted by two pictures with one placed above the other (see Figure 3.1). Target pictures for the future and the past time frames were always contrasted by a picture with the same action in the present time reference, because pictures of past and future are not always easy to distinguish. The items targeting for habitual present were always contrasted with a picture referring to the completed action. An example of a comprehension item is given in Fig 3.1.

(3)	Experimenter:	*Pàpá*	*nó*	*dìì*	ànkáá	*nó*.
		man_{NOM}	the	ate	$\text{orange}_{\text{ACC}}$	the
		The man ate the orange.				

A pair of pictures was presented to the participants and a sentence with the target verb depicting a particular time frame was read aloud by the experimenter. The participants had to point to the picture that matched the spoken sentence. The participants were corrected and given feedback during the practice items but no further feedback was given during the main test. The two tests were performed on different days and each test session lasted for about an hour, with breaks in between. For the scoring, a response was correct when the participants pointed to the picture that matched the time frame encoded in the sentence read out loud by the experimenter.

Fig 3.1. Example of the Akan TART-comprehension, with the target sentence 'the man ate the orange', as in (3). © University of Groningen.

Production TART

For production, a sentence completion task was used, in which participants were prompted to produce the target verb forms. Similar to the Comprehension TART, a total of 18 transitive verbs, with each verb representing actions in three different time frames, present, past and future, were tested. The test began with 6 practice items that consisted of 2 verbs, with each verb inflected for the present habitual, the past and the future to capture all three time frames. Overall, 16 experimental verbs were used, and each (experimental) verb appeared three times; once in each time frame. This made a total of 48 experimental items. All verbs were presented in sentences that began with a lexical adverb corresponding to the time frame of the verbs. A complete list of the verbs is provided in Appendix 2-3. Coloured photographs were used to depict completed, ongoing, and future actions. These actions corresponded to past tense, present habitual, and future tense, respectively. Each item consisted of two pictures, placed side by side, and each picture depicted a different action. Each picture was presented with a root verb written (in bold) above it (see Figure 3.2). This was to avoid verb retrieval difficulties.

(4) Examiner: *Dá bíáá, pàpá nó hwìé mìlìkè nó. Dá bíáá, pàpá nó ..*
Day every, man the pour$_{HAB}$ milk the. Day every man the..
'Every day, the man pours the milk. Every day the man.'

Participant: *nóm̀ mìlìkè nó.*
drink$_{HAB}$ milk$_{ACC}$ the
'drinks milk'

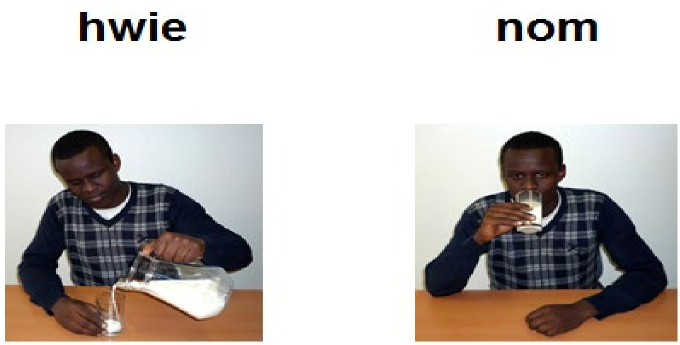

Fig 3.2. Example of the Akan TART-production pictures depicting present habitual aspect in Akan. The Akan verbs t*werɛ*: to write and *kan*: to read, as in (4) are written above the respective pictures. © University of Groningen.

The experimenter first mentioned the verb (above each picture) to the participants in order to prevent them from producing a non-target verb which may also refer to the same action. The experimenter then read out loud a sentence (see Figure 3.2) that described the action in the left picture. The experimenter continued to read the second sentence until he reached the point where the participants were to produce the target verb and the object to complete the sentence. The order of the items was randomized, and no two items in the same time frame were presented consecutively. No feedback was given to the participants except during the trial sessions.

All responses were recorded on a Mobile-Audio digital recorder, and transcribed for scoring by three native speakers. A response was judged correct when the tones were correctly assigned to the verb indicating the correct time frame. A response was incorrect when the time frame of the response was not recognizable. The inter-raters reliability of all three raters showed an item by item agreement of 95% for habitual, 100% for future, and 91% for past verbs produced.

The results on the production test were analyzed both quantitatively and qualitatively. The quantitative analysis consisted of the computation of correct and incorrect responses produced by the participants. For the qualitative analysis, errors were categorized post hoc into four main types, namely substitution, omission, shortened tone and other errors. The substitution errors had six subcategories: (1, 2) past substituted by the habitual, and vice versa (3) past substituted by the present progressive, (4) habitual substituted by the present progressive, (5) future substituted by the habitual, and (6) past substituted by the future. The category 'shortened tone' applied only to a verb in the past form whose last syllable had to be prolonged with its corresponding tone. Other errors were lexical errors (eg. *hwane* 'to peel' instead of *bobɔ* 'to fold').

3.2.3. Statistical Analysis

To test for differences between the NBDs and the agrammatic group, across conditions, *a generalized linear mixed-effects modelling* (GLMM) was performed using the *glmer* function of the lme4 package (Bates, Maechler, and Bolker, 2013) and the *glht* function of the multcomp package (Hothorn, Bretz, Westfall, Heiberger, and Schuetzenmeister, 2013) in R (R Core Team, 2013). Generalized linear mixed-effects regression modelling was used in this analysis because of its robustness in accounting for series of random effects of items and participants. Accounting for the variation across participants and items was critical for the current study due to the relatively small item and group sizes. The dependent variable (Score) of the model was accuracy (1 = correct, 0 = incorrect) with random effects factors for items and participants. The initial complete model included the fixed effects Group (Agrammatic and NBDs), Condition (habitual, future and past) and Task (comprehension and production), and the interactions between these variables. To account for variability across participants and conditions, the model also included random slopes for Condition per Participant. Since the model output showed a ceiling performance of NBD group, only the data of the agrammatic group was considered for further analysis. In this case the fixed effect 'Group' was excluded from the model. The best model (see Appendix 3-2 for the complete model), which included an interaction between Task and Condition, was chosen based on the AIC and the log likelihood ratio tests of the full model with the effect (interaction) in question against the model without the effect (interaction) in question (with significance defined as $p < .05$).

3.3. RESULTS

3.3.1. Tone discrimination

Table 3.1 shows the performance of five agrammatic speakers on the non-linguistic and the linguistic (lexical) discrimination tasks. With the exception of patient P4 (who scored 72%), all the five patients performed at least 90% correct on the non-linguistic version, and above 87% correct on the linguistic version.

Table 3.1. Percentage of accuracy scores on non-/linguistic tone discrimination task

Patients	Non-linguistic tone Discrimination (%)	Linguistic (lexical) tone discrimination (%)
P1	98	93
P2	90	97
P3	92	87
P4	72	87
P10	90	93
Mean	**88.4**	**91.4**

3.3.2. Test for Assessing Time Reference (TART) in Akan

The performance of the agrammatic speakers and the non-brain damaged speakers of Akan, on both comprehension and production of time reference in Akan is captured in Figures 3.3 and 3.4, respectively. The individual scores for both comprehension and production, as well as the full model output are reported in Appendix 3-1 and Appendix 3-4, respectively. The model including the fixed effect Group (Agrammatic and NBD) showed that the accuracy score of the NBDs was significantly higher than the accuracy score of the agrammatic speakers in both comprehension ($\beta = 2.86$, $SE = 0.38$, $z = 7.53$) and production ($\beta = 4.33$, $SE = 0.67$, $z = 6.50$), and there was no pattern observed across conditions (present habitual, past and future) for the NBDs. The data of the NBDs were not included for further analysis, and thus, the fixed effect 'Group' was dropped.

There was a significant interaction between Condition and Task (output of model with no interaction versus a model with a two-way interaction: X^2 (2) = 29.46, $p < 0.001$, with a lower AIC value for the model with interaction). That is, there was a significant dissociation between the future and the habitual time references in the comprehension TART ($\beta = -1.98$, $SE = 0.43$, $z = -4.56$, $p < 0.001$) but not in the production TART ($\beta = 0.69$, $SE = 0.49$, $z = 1.40$, $p = 0.712$).

Comprehension TART

For comprehension, the agrammatic speakers scored significantly lower on past time reference than the future ($\beta = -1.58$, $SE = 0.36$, $z = -4.39$, $p < 0.001$) and the habitual time references ($\beta = -3.55$, $SE = 0.44$, $z = -8.06$, $p < 0.001$). There was a significant difference between the future and the habitual time frames as well (β = 1.98, SE = 0.43, z = 4.56, $p < 0.001$), with the former being more difficult than the latter.

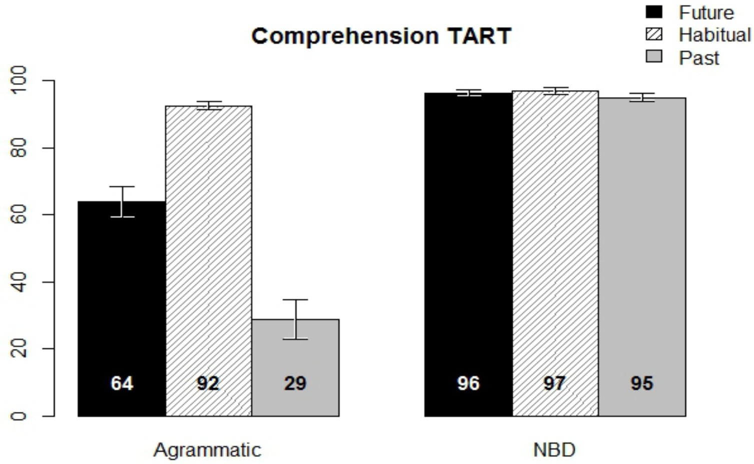

Figure 3.3: Percent mean accuracy scores per condition per group of participants in comprehension-TART, including error bars.

Production TART

In production, there was no significant difference between the future and the habitual time frames (β = -0.69, SE = 0.49, z = -1.40, $p = 0.712$). This explains the significant interaction effect in the model with interactions between Condition and Task. Similar to the comprehension data, the agrammatic speakers were less accurate in producing Akan past time reference than the future (β = -2.02, SE = 0.47, z = -4.34, $p < 0.001$) and the habitual (β = -1.34, SE = 0.43, z = -3.10, $p = 0.02$) time references.

3.3.3. Error Types in production

The distribution of all errors produced by the agrammatic group is reported in Table 3.2. Overall, the substitution errors were the most prevalent (47 out of a total of 82 errors). The past verbs were substituted most frequently by either the present habitual (Hab), present progressive (PP) or the future (FU). Other errors were the use of non-target verbs which could also describe the same actions depicted in the pictures.

Direction of the time reference substitution errors showed that whenever a target time frame was substituted, the agrammatic speakers preferred using a present time frame (89%), followed by the future (9%). The past was least preferred (2%). The agrammatic speakers predominantly substituted the past time reference by a present time reference (either the present habitual or the present progressive). This error type accounts for 27% of the total number of errors. Some of the errors made on the past were shortened duration of tone on the last syllable of the verbs, and this made up 23% of the overall errors produced.

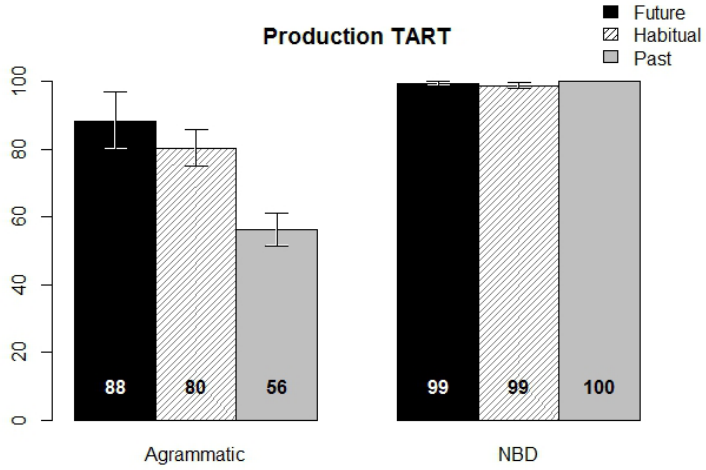

Figure 3.4: Percent mean accuracy scores per condition per group of participants in comprehension-TART, including error bars.

Nonetheless, a further look at the individual errors indicates that not all agrammatic speakers had problems with the past time tone prolongation: Only P2, P6 and P7 made many of these errors (5, 8 and 3 respectively).

In sum, in both production and comprehension, verb forms referring to the past are more affected in Akan speakers with agrammatic aphasia than verb forms referring to either present habitual or future. Nevertheless, in comprehension, there was a dissociation between the present habitual and the future, with the latter being more affected, although both are relatively preserved in production. The error analysis also indicated that whenever there were time frame substitution errors, these errors were towards the direction of the present habitual. The non-linguistic tone task demonstrated that tone per se is relatively preserved in Akan speakers with agrammatic aphasia.

Table 3.2. Distribution of error types

Patient	Substitution						Short vowel duration	Omission	Others
	Ps-Hab	Ps-PP	FU-Hab	Hab-PP	Hab-Ps	Ps-FU			
P1	5	1		2	1				1
P2	2		4	2			5	2	7
P4	2			2		4	1		1
P6	0	0		2			8		0
P7	1	4		1			3		1
P8	2	1		6			1		3
P9	0	4		1			1		1
Total	**12**	**10**	**4**	**16**	**1**	**4**	19	2	14
	Direction of time reference substitution errors (%)								
		Present	Past	Future					
		89%	**2%**	**9%**					

3.4. DISCUSSION

The current study examined whether the observed differences in past versus non-past (present and future) time reference in languages that use morphological inflection also hold for languages that express time reference through grammatical tone. Further, the current study examined whether an impairment (if any) in grammatical tone could be attributed to tone perception in general or to the temporal reference function of Akan verbs. The results demonstrated that reference to past is selectively impaired regardless of the form in which it is expressed. Nevertheless, in comprehension, the agrammatic speakers performed poorer on the future than on the present habitual time frames. The data also showed that the time reference deficit in Akan agrammatic speakers cannot be reduced to their inability to distinguish between (non-linguistic or linguistic) tones, although only five agrammatic patients participated in the non-linguistic tone task. These findings are further discussed in this section.

3.4.1. Difficulties in past time reference regardless of form

The current data provide evidence that in agrammatism, reference to the past is more impaired than reference to the non-past, not only in languages that use morphological inflection, but also in languages that use tone to mark temporal reference. This is consistent with the findings of previous studies in Indo-European languages that express time reference through grammatical morphology (Bastiaanse, 2008, 2013; Bos and Bastiaanse, 2014; Dragoy and Bastiaanse, 2013; Abuom and Bastiaanse, 2012; Bastiaanse et al., 2011; Martínez-Ferreiro and Bastiaanse, 2013), even though some studies did not show such an asymmetry (Burchert et al., 2005; Wenzlaff and Clahsen, 2004; Clahsen and Ali, 2009; Faroqi-Shah and Friedman, 2015; Fyndanis et al., 2018a). This result also provides further evidence for the PADILIH (Bastiaanse et al., 2011). The PADILIH argues that verb forms that make reference to the past require discourse linking. This makes past time reference more complex than present or future time references which are not discourse linked (Zagona, 2013). According to Avrutin (2000; 2006), discourse linking is compromised in Broca's aphasia, and as a result, reference to the past is expected to be affected in agrammatism. Based on the PADILIH, our prediction was that if the problems with past time reference are due to deficit to express this notion by grammatical inflection, the past time reference in Akan should have been spared because tone rather than affix is used. However, past time reference is selectively impaired in agrammatic speakers of Akan, hence, it is not grammatical inflection that is the core of the problem, but expressing time reference to the past by a verb form.

However, the comprehension data showed a deficit in the future time frame as well, and this is not consistent with the predictions of the PADILIH. According to Bastiaanse (2011), who follows Zagona (2003, 2013), the future does not require discourse linking since there is no event yet to link the speaking time to. The PADILIH claims that the future time reference is a subclass of present (Zagona, 2013), and hence, future is not discourse linked. The PADILIH further categorizes the present and the future as non-past, and thus, reference to either of them should be relatively spared. This was not the case in the current comprehension data. Nonetheless, this observed asymmetry between the future and the present (habitual) has also been found in other studies (Martínez-Ferreiro and Bastiaanse, 2013; Nanousi et al., 2006; Bastiaanse et al., 2011). Nanousi et al. (2006) reported that in production, Greek-speaking agrammatic individuals showed a significantly poorer performance in simple future than simple present. Additionally, Martínez-Ferreiro and Bastiaanse, (2013) found that in comprehension, Spanish and Catalan individuals with non-fluent aphasia showed a dissociation between the present and the future, with the former being better preserved, although such difference did not occur in production. Similarly, Bastiaanse et al. (2011) also reported that in comprehension, English, Chinese and Turkish agrammatic individuals showed a dissociation between present reference and future reference, with the latter being more difficult. Furthermore, Zagona's (2003) anaphoric view on the present and the future time references suggests a difference between these two time frames even though both are not discourse linked. This difference lies in how both present and future relate with the speech time and event. While the former shows a simultaneous relationship between speech time and event, the latter does not, since there is no event yet. Further exploration to understand the extent to which comprehension of the future and the present may differ is needed.

On the question of whether grammatical affixes make time reference difficult to process, the observed dissociation between the present and the future could not be attributed to extra processing load which may have been added by presence of the grammatical affix (prefix '*bɛ/be*') in the future time reference. The following are the reasons why we rule out such an interpretation. First, if the extra morpheme posed additional processing demands, the past should have been better preserved than the future, since the past is only marked by tone, and thus, does not have an extra linguistic unit such as an affix. Second, since this dissociation was not replicated in the production data, it is probably not due to the future requiring discourse linking, as argued by Avrutin (2000). Thirdly, the error analysis show that the addition of grammatical affixes does not make a particular time frame difficult to process. The error pattern indicated that some of the participants with agrammatic aphasia preferred the present progressive aspect to the habitual aspect although the Akan verbs in their present progressive form require the use of the prefix '*re-*' in addition to tone. This suggests that grammatical morphology *per se* is not a restraint for verb production, at least for some of the participants of this study.

3.4.2. Tonal height, duration and the past

Time reference in Akan is expressed through grammatical tone, and thus, it is important to tease apart the effect of time reference and tone. The Akan past is distinguished from the present habitual by 1) tonal height and 2) tonal duration. First, for tonal height, all Akan monosyllabic verbs have a high tone (HT) and a low tone (LT) with a longer duration, on the present habitual and the past, respectively. For disyllabic verbs, the present habitual has an LT (on the first syllable) and HT (on the second syllable), while the past has LHLT pattern. Thus, if tonal height (pitch) perception per se was disrupted in Akan agrammatic speakers, then there would be an equal distribution of errors on both the past and the present habitual time references. However, the results indicated that this is not the case – more errors were made on the past than the present habitual. Additionally, the non-linguistic tone as well as the linguistic (lexical and phonemic) tone discrimination tasks which aimed at assessing the general perception of tonal differences showed a relatively intact processing. Although only five agrammatic speakers participated in the non-linguistic tone task, the pattern of errors observed in the TART (which involves grammatical tone) in the other five agrammatic speakers was not different. If tone in general was disrupted, an equal distribution of errors across all time frames should have been observed, since the non-past time references also involve the use of tone. This was not the case. Therefore, the Akan agrammatic speakers' deficit in past time reference cannot be reduced to their inability to perceive tone in general.

Secondly, for tonal duration, the analysis of the error types revealed that some of the errors made on the past verbs were the result of the failure to prolong the tone. This is inconsistent with previous studies that have shown that tonal duration is relatively intact in Thai nonfluent aphasia (Gandour, Ponglorpisit, and Dardarananda, 1992; Gandour et al., 1992one transcortical motor, one global, one left subcortical aphasic, one language-delayed adult, and five normals. The five Thai tones (mid, low, falling, high, rising; Gandour and Dardarananda, 1984). Thai has five tones, with the mid tone and the falling tone having the longest and the shortest tone durations, respectively. Gandour and colleagues found that Thai speakers with nonfluent aphasia have a preserved ability to control relative differences in tone duration associated with the Thai phonological contrast in vowel length (Gandour et al., 1992one transcortical motor, one global, one left subcortical aphasic, one language-delayed adult, and five normals. The five Thai tones (mid, low, falling, high, risinga,b; Gandour and Dardarananda, 1984). Note, however, that Gandour and colleagues examined lexical tone and not grammatical tone.

In the current data, only 3 patients (P2, P6 and P7, see Table 3.1) made a substantial number of errors on the tonal prolongation, therefore, one has to be cautious in concluding that tone prolongation is impaired in Akan agrammatic speakers. Apart from this, the variation among the agrammatic speakers may be due to severity of aphasia (Gandour, Petty and Dardarananda, 1988; Gandour et al., 1992a). Since aphasia severity was not measured in this study, a well-defined acoustic and phonetic investigation of the extent to which tone duration is affected is recommended for future research.

In conclusion, reference to the past is more affected than reference to the non-past in Akan agrammatic speakers, as predicted by the PADILIH. The PADILIH claims that past time reference is difficult because it requires discourse linking, which has been found to be problematic in agrammatism. Therefore, the form in which time reference is expressed, whether through grammatical affixes or tone, does not matter as much as the notion of time. Although some participants with agrammatic aphasia were unable to prolong the tone in the past verb forms correctly for each single item, the current data do not provide evidence to conclude that tone duration was the underlying cause of errors on the past. Taken together, there is a basic effect of time reference, particularly to the past, which may be overlaid by the effect of tonal duration, but which cannot be explained by tonal duration.

CHAPTER 4

Online processing of temporal agreement in a grammatical tone language: An ERP study[1]

ABSTRACT

Previous electrophysiological studies that have examined temporal agreement violations in (Indo-European) languages that use grammatical affixes to mark time reference, have found a Left Anterior Negativity (LAN) and/or P600 ERP components, reflecting morpho-syntactic and syntactic processing, respectively. The current study investigates the electrophysiological processing of temporal relations in an African language (Akan) that uses grammatical tone, rather than morphological inflection, for time reference. Twenty-four native speakers of Akan listened to sentences with time reference violations. Our results demonstrate that a violation of a present context by a past verb yields a P600 time-locked to the verb. There was no such effect when a past context was violated by a present verb. In conclusion, while there are similarities in both Akan and Indo-European languages, as far as the modulation of the P600 effect is concerned, the nature of this effect seems to be different for these languages.

Keywords: Grammatical tone, tense, temporal agreement, Event-related Potentials, Akan

1 This chapter has been adapted from: Tsiwah, F., Bastiaanse, R., Jacolien van Rij & Srđan Popov (in review). Online processing of temporal agreement in a grammatical tone language: An ERP study. *Frontiers in Psychology, Language Sciences.*

4.1. INTRODUCTION

The notion of time is encoded differently across languages in the world. In many Indo-European languages such as English and Dutch, tense inflection on the verb is used to indicate whether the event happened in the past or is currently happening, whereas some Asian languages such as Chinese, Thai and Standard Indonesian use aspectual adverbs for this purpose. Interestingly, Akan, which belongs to the Niger-Congo family, uses grammatical tone to express time reference.

Most of the data on tense (dis)agreement studies come from Indo-European languages, and thus, make the study of time reference strongly biased towards certain devices (such as tense morphology) and certain languages (Klein, 2009). Therefore, it remains unclear whether findings from tense and/or time reference studies are specific to languages that use inflectional verb morphology (such as tense in Indo-European languages) or can be extended to languages that use other means of encoding time reference.

The focus of the current study is on the electrophysiological processing of time reference expressed through grammatical tone, rather than morphological inflection, using event-related potentials (ERP) brain imaging technique. The main question is whether the neural mechanism(s) related to time reference encoding in other languages are specific to those languages, or can be extended to Akan, which is a tonal language that uses tone, for temporal reference.

4.1.1. Tense processing

Tense can be defined as the "grammaticalized expression of location in time" (Comrie 1985). Similarly, aspect is the grammatical specification on the verb that reflects the temporal boundary of an event by indicating whether it is completed (perfective aspect), ongoing (imperfective aspect) or repetitive (imperfective aspect) (Comrie, 1976). Many studies on aphasia have shown that the processing of tense and aspect, which indicate the time reference of an event, are problematic for agrammatic individuals (Dutch: Bastiaanse, 2008; German: Burchert et al., 2005; Wenzlaff & Clahsen, 2004, 2005; Hebrew: Friedmann & Grodzinsky, 1997; Spanish: Gavarró & Martínez-Ferreiro, 2007; Greek: Nanousi et al., 2006). Further, recent studies have demonstrated that not all time frames are equally impaired in agrammatism, and that the time frame referring to the past is usually more susceptible to being impaired than the present and usually also than the future (Bastiaanse, 2013; Bos & Bastiaanse, 2014; Dragoy & Bastiaanse, 2013; Martínez-Ferreiro & Bastiaanse, 2013; Tsiwah et al., 2020). Moreover, reaction time studies on tense processing have shown that healthy adults show longer reaction times for time reference violations caused by a verb in past rather than present tense (Jonkers et al. 2007; Faroqi-Shah & Dickey 2009). Taken together, problems with time reference, through verb inflection, have been shown for many languages, including Indo-European languages that use tense inflection, some Asian languages that use aspectual adverbs, and Akan, a grammatical tone language.

4.1.2. ERP studies on Tense

There are only a few studies that have investigated temporal agreement violations using Event-Related-Potentials (ERPs), and most of them have focused on morphological processing of tense agreement. Using ERPs, Steinhauer and Ullman (2002) presented sentences like (1a) and (1b) to native English speakers to test for tense violations. In their case, the tense violation elicited a left anterior negativity peaking around 300–500 ms after the onset of the verb, and this was followed by a centro-posterior positivity (P600), peaking around 600–900 ms. This biphasic LAN-P600 pattern observed by Steinhauer and Ullman (2002) was taken as indicating morpho-syntactic processing of tense.

(1a) Yesterday, I sailed Diane's boat to Boston.
(1b) *Yesterday, I sail Diane's boat to Boston.

Baggio (2008) tested tense and temporal adverbs disagreement in Dutch sentences like '*Afgelopen zondag lakte/*lakt Vincent de kozijnen van zijn landhuis*' ('Last Sunday Vincent painted/*paints the window frames of his country house'), and replicated the biphasic LAN-P600 pattern that Steinhauer and Ullman (2002) observed in English tense violations. However, Baggio (2008) took these ERP components as signatures of semantic rather than morpho-syntactic processing. Baggio (2008) suggested that the computation of temporal reference is entirely consigned to the semantic processor, and thus, the LAN effect observed for tense disagreement can be taken as reflecting a failure to simultaneously solve the temporal and/or semantic constraints set up by the adverbial and the verb.

Not only were all the above studies carried out for Indo-European languages, which are morphologically marked for tense, but also they used a word-by-word reading task and compared the ERP effect on verbs with different forms. For instance, Steinhauer and Ullman (2002) measured the brain response to sailed (past) versus sail (present), which differ morphologically, and thus the grammaticality differences in the sentences may be confounded by differences in word length and frequency between the word forms that were used.

Dragoy et al. (2012), in a study in Dutch, used a more appropriate methodology and compared time reference mismatches by measuring the ERP effect from the same verb forms, with the different temporal adverbs (in italics) causing the violations.

(2a)	*De kelner*	*[die nu/*zonet*	*de peper maalt]*	*krijgt geen fooi.*
	the waiter	[who now/*a-moment-ago	the pepper grinds]	gets no tip.
	The waiter who is now/a-moment-ago grinding the pepper doesn't get a tip.			

(2b)	*De kelner*	*[die zonet/*nu*	*de peper maalde]*	*krijgt geen fooi.*
	the waiter	[who a-moment-ago/*now	the pepper ground]	gets no tip.
	The waiter who a-moment-ago / now has ground the pepper doesn't get a tip.			

Dragoy and colleagues (2012) found a P600 effect time-locked to the critical verb in present tense (2a), but no ERP effect (between grammatical and ungrammatical sentences in past) was found time-locked to the critical verb in the past (2b). That is, the ERP responses revealed a distinction between the past and the present. In Dutch, the phrase 'the man now ground the pepper' is not readily acceptable, although it can be grammatical in a narrative (e.g. '*…and now Cinderella jumped in the coach'*). For a detailed explanation of the difference between acceptability and grammaticality see Langsford et al., (2019).

The question is whether these ERP components observed in tense violation studies in Indo-European languages are restricted to tense morphology per se, or can be extended to tenseless languages such as Chinese or Thai, that use temporal and aspectual adverbs to make reference to time, or Akan, that expresses tense with grammatical tone. To address the former, Qiu and Zhou (2012) tested (dis)agreement between semantically enriched aspectual adverbs. These aspectual adverbs function like tense and aspect markers, but are free-standing morphemes, that are optional: they are only used when the time (course) of the event is not clear from the discourse. Qiu and Z`hou (2012) used *jiangyao* for future time reference, and *cengjing* for past time reference. However, Chinese also has a bound grammatical morpheme for reference to the past, referred to as a grammaticalized aspectual particle (-*guo*). In their paradigm, they tested sentences in which the aspectual adverb and particle did not match the time frame, set at the beginning of the sentence by a lexical temporal adverbs and temporal noun phrases (*last month and next month*), using ERPs.

A mismatch between noun phrases and both the aspectual adverbs and the aspectual particle elicited a centro-parietal P600 effect, indicating a morphosyntactic violation. Interestingly, violations caused by aspectual adverbs also produced an N400 effect, and according to the authors this is due to the lexical nature of the aspectual adverbs. Apparently, the aspectual particle, as a bound morpheme, is more grammaticalized and is not processed at the lexical semantic level. Moreover, a sustained negativity effect was found after the target words and the final words for all types of temporal markers. This was interpreted as the brain's attempt to repair and create a coherent representation of the sentence.

Summarizing, we can conclude that time reference violation by grammatical morphemes elicits a P600 in Indo European languages (Dutch, English) and in Mandarin Chinese. When the set time frame is violated by an aspectual adverb, that is, a free-standing morpheme, a P600 is elicited, preceded by the N400 that is considered to be a lexical semantic component. This N400 component was also observed in another study of our group in Thai, a language that also uses free-standing aspectual adverbs to refer to the past (Siriboonpipattana et al., in prep).

Only Steinhauer and Ullman (2002) and Baggio (2008) report a LAN preceding the P600. This may be because, as noted above, the words on which they measured in the correct and violated conditions were not the same. For example, Steinhauer and Ullman

(2002) compared *Yesterday she sails…* and *Yesterday she sailed*…. Such a paradigm is common, but may not be optimal. Dragoy et al. (2012) and Qiu and Zhou (2012) compared similar words in a similar context (…*the man who just / now the pepper ground*…) and do not find a LAN. Hence, the P600 is the common component in studies to time reference violations through grammatical morphology. Interestingly, in languages with aspectual adverbs like Chinese (Qiu and Zhou, 2012) and Thai (Siriboonpipattana et al., in prep.) an N400 is reported as well, suggesting that in these constructions, there is a lexical semantic component.

The interpretation of the P600 is slightly different between authors: According to Steinhauer and Ullman (2002), the (biphasic LAN+) P600 represents a morphosyntactic repair process, whereas Baggio (2008) interpreted the biphasic response (LAN+ P600) as a reflection of semantic processing. Dragoy et al. (2012) are somewhere in between, by relating the P600 to discourse linking, which is at the interface of syntax and semantics. Qiu and Zhou (2012) associated the P600 effect found for time reference violations and the bound particle with lexical semantic and morphosyntactic processes.

Therefore, the processing of time reference using ERPs relies on two components, that is, the N400 and P600. These components used to be described as reflecting semantic and syntactic processing, respectively (e.g., Kutas & Hillyard; 1980; Hagoort et al., 1993). However, such a clear-cut dichotomy has been challenged, and alternative accounts have been proposed (e.g., Brouwer, Fitz, & Hoeks, 2012; Kim & Osterhout, 2005; Kolk et al., 2003). Nonetheless, among time referencing studies, the presence of the N400 is mainly understood as indicating tapping into the semantic nature of time reference, mostly in instances in which the tense is expressed via more lexical means. The P600, however, reflects the processing of tense violation, that is, temporal disagreement between the contextually given time reference (usually by an adverb) and inflectional tense morphology. The contribution the current study makes is that it examines time reference processing in an understudied African language in which time reference is expressed neither lexically (i.e., temporal adverbs) nor through inflectional morphology, but rather through grammatical tone.

4.1.3. Features of Akan

The Akan is a tonal language, and has two basic tones: High tone (H) and Low tone (L), which are pronounced with pitch level (Abakah, 2000; 2005b; Dolphyne, 1988). That is, the meaning of a sentence in Akan depends not only on the vowels and the consonants that make up the words, but also on the pitch with which each syllable of the sentence is produced (Dolphyne, 1988; Osam, 2003; 2008). Similar to Chinese, Akan tones have lexical functions (eg. pàpá – 'father', pápá – 'good', pàpà – 'fan'), but unlike Chinese, tones in Akan also serve grammatical functions (see examples 3a, 3b and 3c), and thus, certain grammatical categories such as verb forms (tense/aspect) can be distinguished by tone (Dolphyne, 1988). Below are examples of grammatical tone in Akan.

3a)	*Papa no*	*twèrɛ́*	*lɛ́tɛ̀*
	man the	write-HAB	letter.
	The man writes letter(s)		

3b)	*Papa no*	*twèrɛ́ɛ̀*	*lɛ́tɛ̀*
	man the	write:PAST	letter
	The man wrote letter(s).		

3c)	*Papa no*	*bɛ́twèrɛ̀ɛ̀*	*lɛ́tɛ̀*
	man the	write:FUT	letter
	The man will write letter(s).		

The difference between the habitual and the past is indicated predominantly by tone. The present habitual is marked by a high tone on the final syllable of a verb, hence, tonal marking on the verb for the habitual aspect on a disyllabic verb is Low – High (3a). However, the past has a Low-High-Low tone, with a prolongation of the last vowel (as in 3b). Although the Akan habitual aspect does not locate a specific event in time, and thus, cannot be referred to as the present tense, it is used to express present time (Boadi, 2008). Boadi (2008) suggests that since Akan habitual aspect semantically connotes the idea of present time rather than the past, it is appropriate to refer to it as 'Present habitual'. Akan also has a Past habitual, which connotes an iterative event that occurred in the past. Akan past habitual is indicated by a clause-initial particle 'na', followed by the same form as the present habitual. Since the past habitual requires the use of the past particle, the verb remains habitual, as illustrated in (4).

(4)	Na	papa no	twèrɛ́	lɛ́tɛ̀s	da biaa
	PAST man the	write-HAB	letter day every		
	The man wrote letters every day.				

4.1.4. ERPs in Tonal Languages

The majority of ERP studies in tonal languages have measured the neurophysiological correlates of lexical tone processing at the pre-attentive stage (Fritz et al., 2007), and focused on the inattentive ERP components, such as the Mismatch Negativity (MMN). The MMN is a scalp-recorded event-related brain potential that reflects detection of early cortical stages of auditory processing regardless of whether the participant is paying attention (Näätänen, 2001; Näätänen et al., 2005; Pulvermüller & Shtyrov, 2006, Yue et al., 2014). While the MMN is an index of pre-attentive processing, the P300 reflects an attentive stage of processing, and a more experience driven effects (Frenck-Mestre et al., 2005; Maiste et al., 1995). The P300 effect has been interpreted as an index of discrimination of speech stimuli by phonological information (Frenck-Mestre et al., 2005; Maiste et al., 1995; Zheng et al., 2012). Both the MMN and the P300 have been found in lexical tone processing in tone languages, but they have predominantly been examined the level of categorical perception (Luo et al., 2006; Xi et al., 2010; Yu et al., 2014; 2017; Zheng, et al., 2012).

Kung, Chwilla, and Schriefers, (2014) examined the online interplay of tone and intonation in a larger context (rather than single word stimuli) in Cantonese Chinese. In this study, Cantonese participants were asked to perform a lexical-identification task, in which (critical) words with low tone were placed at the end of either a question or a statement. Note that questions in Chinese end with a rising intonation, and thus, the pitch contour of such words is analogous to the pitch contour of words with a high lexical tone in a regular statement sentence. Their findings indicated a low accuracy in lexical identification and a P600 effect for low tone in questions compared to the same words at the end of a statement. The P600 effect was taken as an indicator of reanalysis, when the listener resolves the conflict of two competing representations that are activated in questions ending with low tones. That is, for question-final words with a low tone, tonal and intonational information interact, and this interaction leads to a conflict between the two representations.

However, despite all these studies, previous ERP studies in tone languages have focused on lexical tones (Xi et al., 2010; Zheng et al., 2012). So far, no study has examined ERP responses when processing grammatical tone.

4.1.5. The current study

The goal of the current study is twofold. First to address the question of whether the neural processing of temporal agreement in grammatical tone languages follows the patterns found in languages in which temporal reference is expressed through inflectional morphology, that is, through affixes. The second goal was to examine whether brain responses for past and present habitual time violations will differ in a grammatical tone language. Should the P600 component be elicited, that would suggest that the expression of the time reference through grammatical tone is similar to inflectional tense morphology. That is, grammatical tone, even though superficially different from inflectional morphology, seems to be processed like inflectional morphology. The ERP component that is of particular interest in the present study is the P600, since this has been consistently observed in studies that have examined tense processing in other languages. Generally, the P600 has been found to index syntactic anomalies that require reanalysis and/or repair (Friederici et al., 2002; Kaan & Swaab, 2003; Osterhout & Mobley, 1995), even though more recent studies have shown that this may not be so straightforward (Brouwer et al., 2012; Kim & Osterhout, 2005; Kolk et al., 2003). The P600 component has a long latency, with its effect starting from around 500 ms after the onset of a target word, and sometimes extending beyond 1000 ms (see Kaan & Swaab, 2003). Depending on the nature of the syntactic anomalies (pure syntactic violations vs syntactic ambiguity), the P600 can have either a centro-parietal or a fronto-central scalp distribution (for review see Hagoort et al., 1999; Friederici et al., 2002).

4.2. MATERIALS AND METHODS

4.2.1. Participants

Twenty-seven native speakers of Akan who were residents of Amsterdam, Netherlands, participated in this experiment. Three (of the 27) participants were excluded from the ERP analysis due to excessive artifacts. All the remaining twenty-four participants (4 females and 20 males; range = 23-35 years; mean age = 24 years) were right-handed, and had normal vision and hearing. All participants had at least a high school level of education, and none had a psychology or linguistics background. Participants were multilingual (Akan, Dutch and English), with Akan being their first language. Prior to testing, we had conversations in Akan with participants to ensure native speakers were recruited. None of the participants reported any speech and/or language, neurological, psychiatric or cognitive disorders. They all signed an inform consent prior to the experiment, and each participant received €15 for their participation. This study was approved by the Research Ethical Review Committee (CETO) of the Faculties of Arts, Philosophy, and Theology and Religious Studies, University of Groningen.

4.2.2. Materials and Procedure

The experimental and the filler sentences were created by using 60 and 30 suitable transitive verbs, respectively. Four variants of sentences were created for each verb. Thus, a total of 240 experimental sentences and 120 fillers were included. The experimental sentences were distributed over four conditions, as illustrated in Table 1: 1) a grammatical present condition in which a temporal adverb referring to a habitual situation matched with a present habitual verb (PresPres); 2) an ungrammatical present time condition in which a temporal adverb referring to the past mismatched with a present habitual verb (PastPres); 3) a grammatical past condition in which a past temporal adverb matched with a past verb (PastPast); 4) an ungrammatical past condition in which a present temporal adverb mismatched with a past verb (PresPast).

Since time reference violations are semantic in nature, the filler sentences, as presented in Table 1, contained equal numbers of semantically congruent and incongruent sentences for both past and present habitual. This was done in order to mask the experimental sentences from the participants. Semantic anomaly was created by choosing a noun that was not semantically plausible in combination with the event (see examples in Table 1). There were 60 semantically plausible filler sentences, and 60 semantically implausible filler sentences. Half of the fillers had present habitual verb forms and the other half past verb forms, with their corresponding temporal adverbs.

All items (both experimental and fillers) were divided into two lists in a Latin square design, meaning that one list contained only one version (grammatical or ungrammatical) of a stimulus. Thus, each participant listened to a total of 180 sentences: 120 experimental items, equally divided into 4 conditions and 30 stimuli each, and 60 filler sentences.

All sentences were spoken by a female native speaker of Akan, and were recorded in a professional recording studio, using the Audacity audio recording and editing software (Audacity: Free Audio Editor and Recorder, 2015). Only grammatical sentences were recorded. The ungrammatical sentences were created from the grammatical sentences through cross splicing, in order to avoid potential confounds such as intonation and loudness. This was achieved by cutting the temporal adverb (at the initial position of each sentence) of a grammatical sentence in a particular time frame (e.g. PresPres), and replacing it with the temporal adverb of a grammatical sentence in another time frame (e.g. PastPast) to create either a PastPres or a PresPast. Finally, volume normalization was applied to all audio files. Since recoding was done in a soundproof booth, recorded sounds files were of high quality and so there was no need to use Audacity's built-in Noise Reduction function.

Table 4.1. Examples of experimental sentences, filler sentences and content questions used in the experiment

	Experimental Sentences			
Condition	**Temporal adverb**	**NP Subject**	**Target Verb**	**NP Object**
1) PresPres	*Da biaa* Day every	*maame no* woman the	*pèpá* mop:Hab	*famu hɔ* floor the
	Every day, the woman mops the floor			
2) *PastPres	*Ennora*, Yesterday,	*maame no* woman the	*pèpá* mop:Hab	*famu hɔ* floor the
	*Yesterday, the woman mops the floor			
3) PastPast	*Ennora*, Yesterday,	*maame no* woman the	*pèpáà* mop:PAST	*famu hɔ* floor the
	Yesterday, the woman mopped the floor			
4) *PresPast	*Da biaa* Day every	*papa no* woman the	*pèpáà* mop:PAST	*famu hɔ* floor the
	*[1]Every day, the woman mopped the floor			
	Filler Sentences			
Congruent	*Ennora* Yesterday	*papa no* man the	*tènáà* sit:Past	*agua no so* chair the on
	Yesterday, the man sat on the chair			
Incongruent	*Ennora* Yesterday	*papa no* man the	*tènáà* sit:Past	Epo *no so* sea the on
	*Yesterday the man sat on the sea			
	Content Questions			
	Maame no na Woman the it was	ɔtènàà she:sit:Past	agua no so? chair the on	
Ex. Question	Was it the woman who sat on the chair?			

Note: [1]In contrast to English, this sentence is ungrammatical in Akan. This was also confirmed in the acceptability ratings where Akan native speakers judged these sentences to be unacceptable.

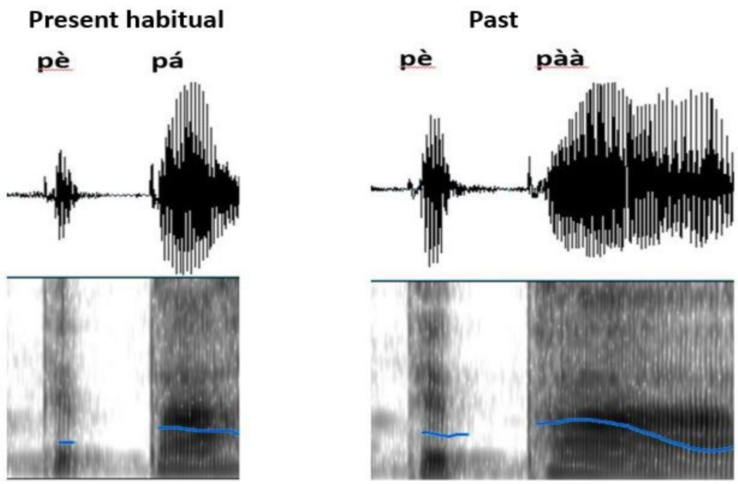

Figure 4.1. Spectrogram showing the pitch information (blue lines) of a present habitual pèpá (mops) and past pèpáà (mopped) verbs.

A spectrographic analysis of the verb conducted on Praat software (Boersma & Weenink, 2008) showed that although the first syllable of both the present habitual and past verbs (compare examples 1 and 3 in Table 1) look identical in terms of tonal height (both have low tone), they differ in terms of duration. Past has a longer tone duration than the present habitual on both the first and the second syllables. This is illustrated on Figure 1.

4.2.3. Acceptability of materials

All items, both experimental stimuli and fillers, were rated by 28 native Akan speakers for acceptability/unacceptability. None of the raters participated in the ERP experiment. The survey was conducted online using Qualtrics Survey software (version XM, Qualtrics). There were 360 sentences in total which were sub-divided into two lists, with 180 sentences in each list. Each participant saw only one list. Six practice sentences preceded each list. Participants were asked to judge whether each sentence they heard was acceptable or not, by indicating 'yes' or 'no'. All the sentences that were included in the experimental set had a consensus rating of at least 80%. Therefore, all items were used in the main experiment.

4.2.4. Procedure

The experimental design was programmed and stimuli presented using E-Prime (version 2.0, Psychology Software Tools, Inc). Participants were seated in front of a computer screen at a distance of 70 to 80 cm, in a dimly lit sound-proof cabin. All stimuli were presented auditorily, and participants had to passively listen to the sentences presented through headphones. Before each sentence, a fixation cross lasting for 500 ms appeared on the screen, prompting the participants of an incoming sentence. Randomly, once in every 3 to 5 items (either experimental or filler), a question was asked about the content of the sentence (e.g., Was it the woman who sat on the chair?). At the presentation of the random content questions, participants were required to actively respond by pressing a button on a game pad. Participants received both written and oral instructions to listen attentively to each sentence, and then answer a content question (if one was presented) by pressing a green or a red button for 'yes' and 'no' responses, respectively. After each content question, participants had 5 seconds to respond with the button press.

Prior to the experimental session, each list began with a practice session, with 6 practice sentences (including 2 content questions). This was to ensure that participants had understood the instructions. Each list was further divided into 4 blocks, with each block having a duration of 6 – 8 minutes, after which there was a break. The experiment lasted for a maximum of 40 minutes, including breaks.

4.2.5. EEG Recording

Continuous EEG data were recorded using the EEGO-Lab system (ANT Neuro Inc, Enschede, The Netherlands) from 32 Ag/AgCl scalp electrodes fitted in an elastic cap (WaveGuard). Data were recorded at a sampling rate of 500 Hz, using the online common average reference, with impedances below 10 KΩ. After data recording, an initial offline data pre-processing was done using the Brain Vision Analyzer software (version2.0.4, Brain Products, GmbH, Munich, Germany), which included re-referencing to the average of the mastoid electrodes, and with highpass and lowpass filtering to cut-off frequencies below 0.1 Hz and above 30 Hz, respectively. Eye-blinks were corrected using an ICA-based eye-blink correction. The segmentation of the data was performed in epochs from 200 ms before the onset of the critical word (verb), until 1200 ms post-onset of the critical word. An automatic artifact rejection was then applied, and all epochs containing activity exceeding +/- 100 μV were excluded. Data were corrected relative to a baseline of 200 ms before the stimulus onset. The data of individual trials were exported to R (R Core Team, 2018) for further pre-processing. The data were down-sampled to 100 Hz, creating 140 time bins (per trial) of 10ms each. For analysis, we calculated the means per condition, participant, and time bin, aggregating over items.

4.2.6. Statistical Analysis

The For the data analysis, we used Generalized Additive Mixed Modeling (GAMM; Hastie & Tibshirani, 1990; Wood, 2017) as implemented in the package *mgcv* version 1.8-24 (Wood, 2017). The package *itsadug* 2.3 (Van Rij et al., 2017) in R version 3.4.4 (R Core Team, 2018) was used for interpretation and visualization of the analysis, and the package *eegkit* 1.0-4 (Helwig, 2018) for visualization of the scalp distribution. GAMM is a non-linear mixed-effects regression method, and thus, does not assume a linear relationship between the dependent variable and a covariate, but rather estimates a relationship using penalized regression splines. GAMM does not require the user to specify the shape of the regression line beforehand, but it is estimated based on the data.

The data of every single electrode in the full-time range of -200 ms to 1200 ms before and after stimulus onset were analysed with the same model specification. The model included a nonlinear effect of Time, to capture the change in ERP over time. This nonlinear effect of Time interacts with Condition, so that the model fits essentially four (potentially different) nonlinear regression lines, capturing the change in ERP over time for each condition. Verb form (present and past) and Grammaticality (grammatical and ungrammatical) were converted into binary variables (i.e. either 0 or 1) named ISPresent, ISUngrammatical, and ISPresentUngrammatical. These binary predictors allowed us to model the nonlinear differences over time between the reference level Past Grammatical and the other conditions. Table 2 shows how the treatment coding relates to the four conditions. On the top row all fixed-effects model terms are presented, with the function *s( )* indicating a smooth function to fit a nonlinear regression line. On the rows the four experimental conditions are listed, with for each condition indicated which model terms contribute to the model's estimation for that condition.

Table 4.2. Fixed-effects model terms and how they relate to each condition.

	Intercept + s(Time)	s(Time): ISPresent	s(Time):IS-Ungrammatical	s(Time): ISPresent-Ungrammatical
Past Grammatical (reference level)	1	0	0	0
Past Ungrammatical	1	0	1	0
Present Grammatical	1	1	0	0
Present Ungrammatical	1	1	1	1

For each single electrode analysis, the GAMM model included random effects for participants. For each combination of participant and condition (Tense and Grammaticality), we added a non-linear random effect with non-linear effect over time to account for variation in the time course by participants and conditions. We chose the maximal random effects structure to maximally reduce autocorrelation, which will result in the most conservative estimates (cf. van Rij et al, 2019). To account for the remaining autocorrelation in the residuals, we also included an Auto-regressive (AR1) model that corrected the confidence intervals of the model estimates accordingly. As the data were not normally distributed, we fitted the nonlinear regression model with a link function for a scaled-t distribution.

The model was fitted with the maximum likelihood (ML) as smoothing parameter estimation method (cf. Wieling, 2018). We used summary statistics and visualization of the model's predictions to assess significance (cf. van Rij et al, 2019), but not model comparison. Because we included nonlinear random effects for each individual time-varying event (i.e., participant-condition combination), the fixed-effect pattern was captured by the random effects when the fixed-effects smooths were excluded. As a result, the model comparison procedure did provide much information.

Although GAMMs have recently been used in a number of ERP studies on language processing (Kryuchkova et al., 2011; Baayen et al., 2015; Meulman et al., 2015; Nixon et al., 2017), it is still a relatively novel statistical method. Therefore, we also performed a more traditional ANOVA analysis as a supplementary analysis. Since the GAMM results showed that the ERP effect only started from around 400 ms and lasted until 1200 ms, the average amplitudes of the ERP waveforms in the time-windows of 400-600 ms, 600-800 ms, 800-1000 ms and 1000-1200 ms after the onset of a stimulus were analysed. To avoid Type 1 errors, we ran a multiple comparison correction using the False discovery rate correction to the p-values after follow-up analyses. We followed the procedure of Meulman et al., (2015) by using the ezANOVA R package (Lawrence, 2013) to perform the grand mean analysis.

4.3. RESULTS

Figure 2 shows the grand means for the four conditions (± standard error of participant means) for electrode Fz. For the past tense, the data shows a clear difference in the ERPs elicited by grammatical (black lines) and ungrammatical (red lines) verb forms. The amplitudes measured during the processing of ungrammatical verb forms (center panel of Figure 2) display a positive going trend from around 400 ms after verb onset, whereas the amplitudes measured during processing the grammatical verb forms stay negative. This difference is diminished for the present verb stimuli (right panel of Figure 2). See Appendix 4-1 Figure 1 for the grand averages of electrodes Cz, C3, and POz, the classical electrodes where P600 is detected.

4.3.1. GAMMs analyses

The effects of Time, Verb form and Grammaticality were analysed with GAMMs, as explained in the preceding section. Each electrode was analysed separately. The correlation between the model fit and the data was on average 0.90 (range 0.83-0.97), and the adjusted R^2 of the models (which was almost identical to the explained deviance for these models) was on average 0.81 (range 0.67-0.94), indicating an excellent fit of the data. The difference in response to the grammatical and ungrammatical verb forms in the past tense condition was found to be significant in the fronto-central electrodes: The summary statistics (see Appendix 4-2 Figure 2) indicated that the difference between grammatical past verb form and ungrammatical past verb form (captured by s(Time, by=*IsUngrammatical*)) was significant in the electrodes C3 ($F(2.001, 12523.975) = 4.65$; $p < .01$), CP1 ($F(2.001, 12512.465) = 4.86$; $p < .01$), CP2 ($F(2.000, 12510.917) = 4.15$; $p = 0.016$), Cz ($F(2.001, 12416.119) = 4.98$; $p < .01$), FC1 ($F(2.001, 12442.790) = 3.86$; $p = 0.021$), Fz ($F(2.001, 12422.084) = 4.68$; $p < .01$), and P8 ($F(2.000, 12787.877) = 3.91$; $p = 0.020$). The electrodes FC2 ($F(2.001, 12399.588) = 2.40$; $p = 0.091$) and P7 ($F(2.000, 12724.398) = 2.60$;

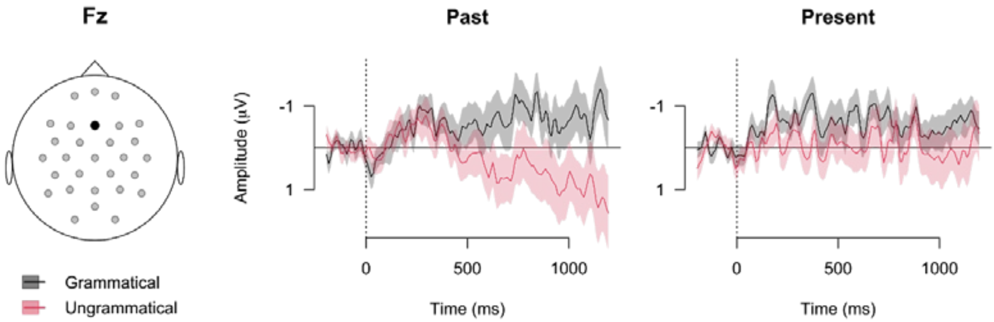

Figure 4.2. Grand averages of electrode Fz (error bars: ±1 SE, based on participant means). The x-axes show the time (in ms) from verb onset, and the y-axes show the grand means of the recorded amplitudes (negative upward). Left: Electrode position. Center: Grand averages of the grammatical past tense sentences (black line) and the ungrammatical past tense sentences (red line). Right: Grand averages of the grammatical present tense sentences (black line) and the ungrammatical present tense sentences (red line).

$p = 0.075$) showed marginally significant effects. The difference between Past Grammatical and Present Grammatical (captured by s(Time, by=*IsPresent*), see Appendix 4-2 Figure 2) was only significant for electrode POz ($F(6.511, 12669.473)=2.28$; $p=0.022$). Finally, the difference between the effect of Grammaticality in the Past verb form and in the Present verb form was significant for electrode CP1 ($F(2.002, 12512.465)=3.10$; $p=0.045$) and marginally significant for electrodes C3 ($F(2.000, 12523.975)=2.97$; $p=0.051$), CP2

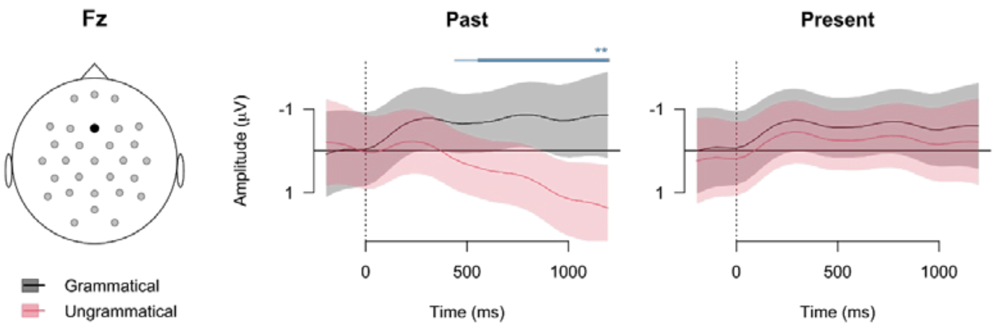

Figure 4.3. Model estimates (i.e., summed effects, with random effects excluded) for the GAMM fitting the data of electrode Fz (error bars: pointwise CI, 95%). The x-axes show the time (in ms) from verb onset, and the y-axes show the estimated amplitudes (negative upward). Left: Electrode position. Center: Model estimates of the grammatical past tense sentences (black line) and the ungrammatical past tense sentences (red line). Right: Model estimates of the grammatical present tense sentences (black line) and the ungrammatical present tense sentences (red line). The blue line in the center panel indicates the time window in which the model predicts a significant difference between the two grammaticality conditions. (The thin line is the estimated difference based on pointwise confidence intervals, whereas the thick lines are the estimated differences based on the simultaneous confidence intervals.)

(F(2.000, 12510.917)=2.70; p=0.067), and P8 (F(2.002, 12787.877)=2.70; p=0.067).
To inspect the interaction between Time, Verb forms, and Grammaticality as estimated by the model, we visualized the summed fixed-effect predictions, as in Figure 3 for electrode Fz (see Appendix 4-3 Figure 3 for model estimates for Cz, C3 and POz). the central electrodes (see Figure 3), but no significant differences in Grammaticality for the Present verb form. Most differences between the grammaticality conditions for the Past.

Note that these summed effects additionally include the intercept and its variance, but no random effects. The summed effects showed significant differences in Grammaticality for the Past verb form in verb form started around 500 ms after verb onset (see Figure 4, Right panel) and lasted until the end of the analysis window.

4.3.2. Traditional Anova analysis

Since the GAMMs results showed that the ERP effect only started from around 500 ms and lasted until 1200 ms, the average amplitudes of the ERP waveforms in this time-window after the onset of a stimulus were used for the ANOVA analysis. To make this analysis comparable to the GAMM, we performed a single electrode analysis on Fz, Cz, C3 and Pz. For both Fz and Cz, there was only a main effect for Grammaticality (F(1,23) = 6.009, p = .022 and F(1,23) = 6.785, p = .016, respectively). There was no main effect for Verb form nor an interaction between Verb form and Grammaticality (Fz: F(1,23) = 1.530, p = .229; Cz: F(1,23) = 2.696, p = .114). The C3 electrode, however, showed a significant interaction between Verb form and Grammaticality (F(1,23) = 5.034, p = 0.035). Follow-up analysis showed significant differences in grammatical and ungrammatical sentences only in the past tense condition (F(1,23) = 6.302, p = .039, FDR multiple comparison corrected) and not in the present verb form condition (F(1,23) = 0.136, p = .716, FDR multiple comparison corrected). Lastly, for electrode Pz, there was no effect of Grammaticality (F(1,23) = 1.703,

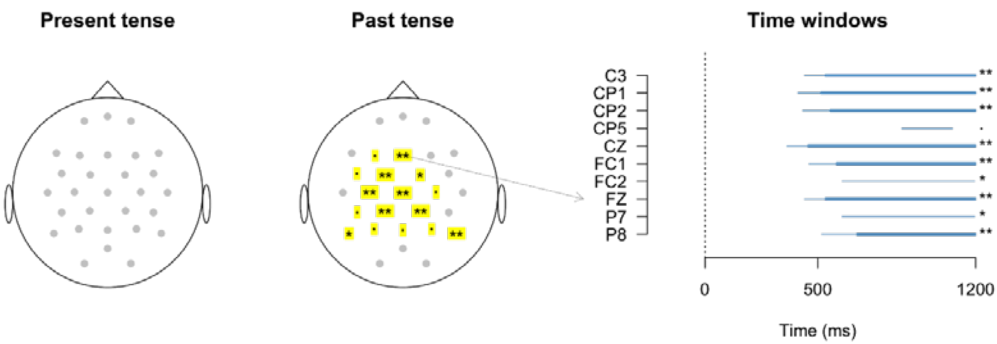

Figure 4.4. Predicted differences of the GAMM analyses per electrode. Left panels: For the Present tense and Past tense conditions, respectively, the significant differences between grammatical and ungrammatical verbs are indicated with significant stars: '***' = p<0.001; '**' = p<0.01; '*' = p<0.05; '.' = p<0.1. Significant differences are only predicted for the Past tense conditions. The right panel represents the time windows in which the GAMM analyses predict the difference to occur. (The thin lines are the estimated differences based on pointwise confidence intervals, whereas the thick lines are the estimated differences based on the simultaneous confidence intervals.)

p = .205 and Verb form (F(1,23) = 0.016, p = .899)), nor the interaction between them (F(1,23) = 0.339, p = .566).
In summary, while the ANOVA analysis showed a grammaticality effect for Fz, and Cz and no effect for Verb forms, it was not sensitive enough to capture their interaction (unlike GAMMs), except for C3 which showed a grammaticality effect for past verb forms (and not present verb forms) condition. Pz showed no effect at all, suggesting a fronto-central P600-like effect.

4.4. DISCUSSION

The current study investigated the effect of grammatical tone on the processing of temporal (dis)agreement in Akan, using event-related potentials (ERP) brain imaging technique. Our aim was, first to examine the electrophysiological processes involved in temporal (dis)agreement in a grammatical tone language, and how they relate to the morphosyntactic processing of tense reported for Indo-European languages. The second goal was to examine whether the brain responses revealed by the ERP components for past and present habitual time violations differ in a grammatical tone language. In this section, we will first discuss the ERP findings in relation to the previous ERP studies on tense in Indo-European languages (Baggio, 2008; Steinhauer & Ullman, 2002; Dragoy et al., 2012), and then the differences in neural mechanism that underlie past and present habitual verbs.

4.4.1. Tense and Grammatical Tone in Temporal Agreement Processing

Cross-linguistics studies on temporal (dis)agreement in Indo European languages have found that tense violations elicit a centro-posterior positivity (P600), peaking around 600–900 ms, sometime preceded by left anterior negativity (LAN: peaking around 300–500 ms after the onset of the verb). This biphasic LAN-P600 pattern has been observed by a number of studies that looked at tense in Indo-European languages such English (Steinhauer & Ullman, 2002) and Dutch (Baggio, 2008). While Steinhauer and Ullman (2002) took this LAN-P600 pattern as indices of morpho-syntactic processing of tense, Baggio, (2008) treated these ERP components as a signature of temporal-semantic processing. Dragoy et al., (2012) replicated only the P600 ERP component in sentences where a past context was violated by a present verb forms in Dutch. Dragoy and colleagues found no effect when the present context was violated by past tense.

Our findings are that temporal disagreement in Akan also elicits a P600-like ERP component. Nonetheless, this ERP effect was evident only when temporal violations were caused by past verb forms. This positive ERP effect observed in the current study differs in some ways from the P600 observed by Steinhauer and Ullman (2002) and Baggio (2008). This may be the result of differences in materials and study designs. Note, that the above-mentioned studies, with exception of Dragoy et al. (2012), only tested temporal disagreement caused by present verbs, whereas the current study tested both past and present verb violations. Furthermore, these studies measured the ERP effect on different verb forms. Therefore, the elicitation of the ERP components may not necessarily have been associated with temporal disagreement per se, but rather due to differences in factors such as length (or differences in forms) and frequency between the word forms that were used. However, like our study, Dragoy and colleagues' (2012) compared true time reference mismatches by using the same verb forms with differences only in the temporal contexts (e.g. *De kelner [die **nu/zonet** de peper **maalt**] krijgt geen fooi*: 'The waiter who is **now/a-moment-ago** grinds the pepper doesn't get a tip'). The fact that, in contrast to our study, Dragoy and colleagues did not find an effect when violations were caused by past verb forms will be further discussed later.

One of the ways in which the P600 component observed in the current study differs from previous reports of this component in Indo-European languages is its latency. The positivity observed in this study was earlier and lasted longer than the P600 reported by Steinhauer and Ullman (2002) and Baggio (2008). In our case, the P600-like effect emerged from around 400 ms and lasted until around 1200 ms. Generally, this is not inconsistent with the long-lasting nature of the P600 component whose effect usually extends beyond the end of the target word (see Kaan & Swaab, 2003; Osterhout & Mobley, 1995). Furthermore, the longer-lasting positive effect is consistent with the results of Dragoy et al. (2012) who also tested pure time reference violations and showed a longer lasting P600-like effect peaking around 1200 ms after stimulus onset. This suggest that pure time reference violations (such as in Dragoy et al. 2012 and the current study) evoke a longer-lasting P600 effect. However, further investigation is needed to establish this tentative interpretation.

There are two more possible explanations for the long lasting P600 latency found in this study. First, the early emergence of the P600 in the current study can be attributed to the presence of tone in general, which results in 'phono-syntactic' rather than the morpho-syntactic processing in Indo-European languages. Previous ERP studies that have investigated (lexical) tone processing in tonal languages have observed an early positivity (such as the P300) which has been taken to be an index of discrimination of speech stimuli by phonological information (Maiste et al., 1995; Frenck-Mestre et al., 2005; Zheng et al., 2012). Note that these studies measured lexical tone processing, and thus, the nature of the positivity may not be the same as grammatical level tone processing. Secondly, a spectrographic analysis of the verbs (e.g. past: *pèpàà* 'mopped'; present habitual: *pèpá* 'mops') indicated that although the tonal height of the first syllable of both past and present habitual verbs are identical in terms of tonal height, they tend to differ in length, with the past having a relatively longer tone duration than the present habitual (see Figure 1 above). That is, the past and the present habitual do not only differ (in height and duration) at the last syllable but also (in duration) at the first syllable. This finding has not been described in the literature before (Akan is a very understudied language), nonetheless, we suggest that it is due to an assimilation process in the Akan past verbs, resulting from the prolonged tonal duration of the last syllable. Consequently, the parser recognizes two disambiguation points when processing past verbs violating present context, with the first disambiguation point occurring at an early stage of processing. Contrarily, in Indo-European languages, there is only one point of disambiguation on the target occurring at the end of the verb (Dutch: Baggio, 2008; Dragoy et al., 2012; English: Steinhauer & Ullman, 2002). Taken together, the latency of the P600-like ERP component in the current study portrays the uniqueness of Akan verb morphology in which tone rather than affixes is used to indicate time.

Another way in which the observed positive effect in this study differs from that found in other languages is the scalp distribution of the P600. The P600 effect elicited by the past verb violations was localized fronto-centrally, and stronger centrally, as opposed to the centro-posterior P600 effect observed in Indo-European languages (Baggio, 2008; Dragoy et al., 2012; Steinhauer & Ullman, 2002). These distributional differences may be due to the differences in the type of violations used in these studies. In their review of P600 studies, Hagoort, Brown & Osterhout, (1999), argue that the distribution of the P600 evoked by ambiguity resolution (reanalysis–related P600) is different from P600 elicited by pure syntactic violations (repair-related P600). Building on this, Friederici et al. (2002) found a P600 with a more fronto-central distribution for violations which were syntactically ambiguous in nature (such as garden path sentences), and a central-posterior P600 for sentences with morphosyntactic violations. While Friederici et al. (2002) attribute a fronto-central P600 to a general syntactic revision, Kaan and Swaab, (2003) specifically associates it with discourse level complexity which requires revision. Since past time reference has been found to involve discourse level processing (Bastiaanse, 2013), we argue that the frontocentral P600 found in this study is indicative of processing a violation at the discourse level (Kaan & Swaab, 2003).

4.4.2. Differences in the Processing of Past and Present Habitual

The results of the current study show that the processing of present habitual and past verb forms in Akan involve different neuronal processes. While past verb violations elicited a P600-like ERP component, there was no such effect when violations were caused by present verbs. This is consistent with the dissociation found between the past and the present (habitual) in clinical population studies (Bastiaanse, 2013; Bos and Bastiaanse, 2014; Tsiwah et al., 2020). Tsiwah and colleagues (2020) demonstrated that agrammatic aphasic speakers of Akan showed a dissociation in processing past and present habitual verbs in Akan, with the former being more difficult than the latter. The differences in processing between past and present verb forms has also been reported in studies that used reaction times as a reflection of temporal reference violations (Jonkers et al. 2007; Faroqi-Shah & Dickey 2009). This shows that regardless of how time reference is expressed, whether

through affixes (as in Indo-European languages) or tone (as in Akan), the processing of present and the past times show different underlying neural processes.
However, the direction of the past and present habitual difference in the current study is not in line with what was observed by Dragoy and colleagues (2012) in Dutch. Dragoy and colleagues found the P600-like effect when violations were caused by present tense verbs, but there was no effect when past verb forms caused the violations. This inconsistency can be attributed to the differences in the usage of present (habitual) and past verb forms in these languages (Akan and Dutch). First, the absence of an effect in the Akan present habitual may have been caused by the extra aspectual information on top of the temporal violation itself, unlike the present tense verbs in Indo-European languages which strictly represent reference to the moment of speaking. Although the Akan present habitual is used to express present time, it can also be used for other kinds of aspectual information such as state of an action or truth proposition (Boadi, 2008). Nonetheless, the notion of present time in the present habitual in Akan is not replaced by this extra aspectual information, yet it could be overlaid by this background eventuality adding up to the temporal nature of the verb.

Turning to the presence of a P600-like effect in past verb form violations, this seems to be caused by the fact that using a past verb in a habitual context in Akan is 'unpreferred' (see Kaan & Swaab 2003 for more on nonpreferred sentences) rather than it being ungrammatical. Although the violations in the past condition (**Da biaa papa no hwànèè ankaa*: 'Every day the man peeled oranges') are considered to be past habitual construction in Indo-European languages (such as English and Dutch), and, thus, are acceptable, this is not the case in Akan. Akan past habitual is represented by a clause initial particle '*na*', indicating a past context. Note that the offline acceptability ratings showed that native Akan speakers judge the above example as unacceptable. Therefore, we argue that the elicitation of a P600-like effect by past verb forms shows that they are non-preferred constructions in Akan. This is in line with the findings of Kaan and Swaab (2003) who reported that non-preferred sentences elicit a late P600 effect distributed fronto-centrally, which was the case in the current study.

In conclusion, the P600-like effect observed in Akan sentences with grammatical tone violations shows both similarities and differences with results from studies on the same topic in Indo-European languages and in languages that use aspectual adverbs. The similarity is the P600 that arises in all languages in at least one condition, no matter whether time reference is achieved through bound morphemes, free-standing morphemes or grammatical tone. The fact that this component is not found in all conditions, may be due to language-specific characteristics as well as methodological issues. This may also explain why a LAN is reported in some studies, but not in others.

4.4.3. Limitations of the study

To further examine the absence of an ERP component in the present habitual, an important thing to consider for future research will be to use acceptability or grammaticality judgement (after each stimulus presentation) during the experiment instead of the random content questions adopted for the current study. Although the offline grammaticality judgement task revealed that native Akan speakers judge a past context violated by a present habitual verb (eg. *Ennora, papa no hwàné ankaa*; 'Yesterday, the man peels oranges) to be ungrammatical, this effect of ungrammaticality was not reflected in the ERP experiment. Note, however, that the Akan speakers who participated in the offline grammaticality judgment task were different from those who participated in the ERP experiment.

Furthermore, we have argued that the absence of an ERP effect in the present habitual verb form violations may be due to the extra aspectual information (such as truth proposition and state) contained in the Akan present habitual. That is, on top of the notion of present time carried by the Akan present habitual verb, there is also background eventuality (Boadi, 2008) which may overlay the effect of the present time. To resolve this, future studies can consider using the Akan present progressive (e.g. *Sesiaa papa no (è) twìtwá brood no*; 'Right now, the man is cutting the bread') which carries only the notion of time (an ongoing event). Although the Akan present progressive is indicated by a prefix (in addition to the tonal marking) in written form, this prefix becomes covert when used verbally. Thus, in an auditory paradigm, such as used in the current study, the use of the Akan present progressive will be comparable to some extent to the Akan past which is purely marked by tone and duration.

Lastly, we have barely scratched the surface of tone processing in Akan. The current study focused on grammatical tone processing using Akan verbs. However, like Chinese, Akan also has lexical tone. That is, two words can be differentiated in meaning on the basis of their tonal markings (eg. *pàpá* 'father'; *pàpà* 'fan'). Therefore, it is interesting for future studies to systematically compare lexical and grammatical tone processing in one experimental paradigm, in the same language, and with the same participants. This will give more insight into the distinct electrophysiological mechanism(s) that underlie tone processing both at the word and sentence level.

CHAPTER 5

General discussion and future research directions

This chapter contains the overall discussion of the major findings of this project in relation to the research questions that were raised in Chapter 1 of this dissertation. To recap, the entire project aimed at understanding how the distinctive realization of Akan verb morphology is processed in the brain, and how this relates to what has been discovered in other languages. This is interesting because, in Akan, unlike in any other language that has been subject to neurolinguistic study, grammatical tone is used to distinguish past from present time reference on the verb. We used a set of offline behavioral methods, such as a sentence completion and sentence-picture-matching tasks, as well as an online electrophysiological method: Event related Potentials (ERPs). In the next section, all the major findings and their implications will be discussed. The chapter will conclude with limitations of this project as well as recommendations for future research.

5.1. OVERVIEW OF MAJOR FINDINGS

5.1.1. Tone perception and its hemispheric lateralization

The first major issue addressed in this dissertation is described in Chapter 2. This chapter examined grammatical tone perception in left and right hemisphere damaged speakers of Akan, as lexical tone perception has been in other languages. The question was whether there is a difference between pitch used for linguistic (such as grammatical tone) and for non-linguistic (pure tone perception) functions in left and right hemisphere damaged Akan speakers. To test this, a grammatical tone perception task as well as a pure tone discrimination task was administered in these two groups of brain-damaged individuals.

There has been a long-standing controversy regarding the hemispheric lateralization of speech prosody processing, and this has led to the proposal of two dominant but opposing accounts, namely the *function-dependent brain asymmetry* and the *acoustic-dependent brain asymmetry* models. The function-dependent brain asymmetry model predicts left hemisphere lateralization when pitch information is linguistically relevant (Van Lancker, 1980; for a review, see Zatorre & Gandour, 2009), and right hemisphere lateralization when pitch variations are processed primarily as acoustic (linguistically irrelevant) units. According to this account, brain damage to the left hemisphere will lead to difficulties in lexical/grammatical tone perception whereas damage to the right hemisphere will result in deficits in non-linguistic tone perception. In contrast, the acoustic-dependent brain asymmetry model, proposes that pitch information is processed on the basis of the acoustic signals it provides, irrespective of its functions, and, thus, lexical tone processing is lateralized to the right hemisphere (Ge et al., 2015; Poeppel, 2003; Ren et al., 2009; Sidtis & Van Lancker-Sidtis, 2003; Van Lancker & Sidtis, 1992; Zatorre & Belin, 2001). Consequently, brain damage to the right hemisphere should result in difficulties in perceiving both linguistic (lexical/grammatical) and non-linguistic tone.

The results of our study, as discussed in Chapter 2 of this dissertation, did not reveal a clear-cut pattern that precisely fits the assumptions of either of these two models regarding the hemispheric lateralization of linguistic and non-linguistic tone perception. The data from the individuals with left hemisphere damage showed that the perception of linguistic tone was poorer than non-linguistic tone. This suggests a dominant involvement of the left hemisphere in grammatical (linguistic) tone perception, whereas this hemisphere is less involved in non-linguistic tone perception, and, thus, lending support to the function-dependent brain asymmetry model. However, this model assumes that individuals with right hemisphere damage should be less prone to impairment in perceiving grammatical tone. This was not supported by the current data. In fact, the individuals with right hemisphere damage performed as poorly as on grammatical tone perception as the individuals with left hemisphere damage. Furthermore, the individuals with right hemisphere damage showed no difference in their ability to perceive linguistic and non-linguistic tones, suggesting an involvement of the right hemisphere in both grammatical tone and pure tone perception, as predicted by the acoustic-dependent brain asymmetry model.

What is clear from the current study is that both groups with left and right hemisphere damage showed reduced performance in both linguistic and non-linguistic tone perception, as compared to the non-brain damaged group. This, to some extent, suggests a bilateral hemispheric involvement in tone perception, regardless of linguistic relevance. A strict dichotomy in hemispheric lateralization for either linguistic or non-linguistic tone perception was not supported by the findings of this study. This means that claiming one or the other as the sole explanatory model on the basis of the current data is impossible. However, according to Zattore and Gandour (2009), these two models should not be treated as mutually exclusive, and thus, aspects of each model need to be integrated into a more comprehensive model of bilateral hemispheric involvement in tone processing. What precisely should constitute such a model is beyond the scope of this study, considering the limited sample size.

In addition, the finding that the individuals with left hemisphere damage showed impairments on grammatical tone comprehension led to the question of whether the underlying problem was grammatical tone per se or time reference related. Note that only past and present habitual verb forms were tested in the study reported in Chapter 2. Consequently, this project also examined both comprehension and production of time reference (past, present habitual and future) in Akan individuals with agrammatic aphasia (with left hemisphere brain damage), as discussed in the next section.

5.1.2. Differences in past and non-past time reference are not language specific

The second major issue that the current project aimed to address was whether the differences in sentence processing between past and non-past time reference observed in earlier literature, are restricted to languages with morphological verb inflections or whether they also manifest in languages that express time reference through grammatical tone. This was addressed in the second study, described in Chapter 3 of this dissertation, which focused on how time reference is processed in Akan individuals with agrammatic aphasia. A follow up study, which is the third study of this dissertation, reported in Chapter 4, also sought to investigate the electrophysiological underpinnings of past and present habitual processing in non-brain damaged individuals.

To address these questions, the second study adopted both a sentence completion and a sentence-picture-matching task to investigate how time reference was produced and comprehended among Akan speakers with agrammatic aphasia. Additionally, to examine whether tone perception in general was intact, five of the agrammatic speakers performed two tonal discrimination tasks: non-linguistic and linguistic (lexical). The rationale behind this study was that if comprehension and production of grammatical affixes, which are used for time reference in Indo-European languages, are the cause of the underlying deficits that agrammatic speakers have in time reference processing (particularly the past), then Akan agrammatic speakers should show no impairment. This is because in Akan, it is grammatical tone rather than affixation that is used for time reference. If the use of grammatical affixes is not the underlying deficits agrammatic speakers have in past time reference, but rather there is a deficit in the ability to refer to the past through linguistic means, then Akan agrammatic speakers should also have problems in processing time reference, particularly time reference to the past.

The results showed that in both comprehension and production, Akan agrammatic speakers showed more difficulties in processing past than both present habitual and future time reference. This is consistent with previous findings in other languages and across different clinical populations (agrammatic aphasia – Dutch: Bos & Bastiaanse, 2014; Spanish: Martínez-Ferreiro & Bastiaanse, 2013; Swahili: Abuom & Bastiaanse, 2012; Alzheimer's Disease: Irish, 2016; Kim & Thompson, 2004; semantic dementia: Irish, 2016). Additionally, studies that used reaction times to reflect processing of temporal reference violations have also showed this dissociation (Jonkers et al., 2007; Faroqi-Shah & Dickey 2009). These results also supported the PAst DIscourse LInking Hypothesis (PADILIH: Bastiaanse 2013). The PADILIH argues that verb forms that make reference to the past require discourse linking, and discourse linking is hard for individuals with agrammatic aphasia (Avrutin, 2000; 2006). Thus, reference to the past is more complex than reference to the present or future time, which are not discourse linked (Zagona, 2013).

However, the comprehension data reported in Chapter 3 showed that Akan agrammatic speakers performed more poorly in comprehending future than present habitual verb forms. This dissociation is not consistent with the predictions of the PADILIH. One might attribute the difficulties in perceiving the future time frame in relation to the present habitual to the presence of a prefix on the future verb form. However, the fact that the past verb form which was purely marked by tone was still worse than the future, suggests that the use of a prefix per se cannot account for this dissociation. Furthermore, if the use of the prefix in general was the cause of the difficulties with the future, then a similar pattern of impairment should have emerged in the production data, which was not the case. This observed asymmetry between the future and the present (habitual) in comprehension has also been found in other studies (Spanish: Martínez-Ferreiro & Bastiaanse, 2013; Greek: Nanousi et al., 2006; Turkish: Bastiaanse et al., 2011). It is important to note that Zagona's (2003) anaphoric view of present and future time reference assumes a difference between these two time frames, even though both are not discourse linked. This emanates from how both present and future relate to the speech time and event: Present has a simultaneous relationship between speech time and event, whereas the future does not, since there is no event yet. While this might be a plausible explanation for the dissociation observed, it is not clear why the difference exists in comprehension and not in production. One potential explanation could be the fact that in comprehension, the picture depicting future time frame was always contrasted with a present picture in which an action is taking place.

It is possible that the agrammatic individuals showed a preference for present because it contained an action whereas there was no action yet in the future pictures. However, further exploration is needed to understand the extent to which comprehension of the future and the present may differ.

Recapitulating the discussion on why past time reference was worse than both present habitual and future, the PADILIH (Bastiaanse 2013) argues that discourse linking is required when referring to the past, since the time of speaking does not coincide with the event time (Zagona 2003; 2013). Future reference, however, is not bound to the discourse since the event has not yet taken place. Similarly, reference to the present requires that the time of speaking coincides with the time of the event, and, thus, no discourse linking is required. Taken together, while past time reference involves discourse level syntax, present and future time reference do not. The Event-Related Potential study with non-brain damaged speakers of Akan in Chapter 4 of this dissertation lends support to this assertion. One of the goals of this study was to address the question of whether there are differences in the brain responses for past and present habitual time violations in Akan. In this study time reference violations by a past verb elicited a P600 effect whereas time reference violations by a present verb did not. That is, at the electrophysiological level, past and present verbs are processed differently. The observed P600 effect for past verb violation was distributed over the fronto-central region of the scalp. Kaan and Swaab, (2003) specifically associate such a fronto-central P600 with discourse level complexity which requires revision. Since past time reference has been suggested to involve discourse level processing (Bastiaanse, 2013), we argue that the frontocentral P600 found in this study is indicative of processing a violation at the level of discourse whereas the present habitual does not involve such processes.

To conclude, regardless of how time reference is expressed, whether through affixes (as in Indo-European languages) or tone (as in Akan), the processing of past and non-past time reference show different underlying neural processes. For individuals with agrammatic aphasia, processing past time reference is problematic because of discourse linking, as argued by the PADILIH. This may suggest that the problems Akan individuals with left hemisphere damage showed in grammatical tone perception in Chapter 2 may have been driven to some extent by past time reference and not necessarily grammatical tone per se.

5.1.3. Brain responses to grammatical tone processing

The last issue raised in Chapter 1 of this dissertation was the question of how temporal information in a grammatical tone language, such as Akan, is processed online. To be more precise, what are the electrophysiological correlates of temporal agreement in grammatical tone languages, and how do they compare to morphosyntactic processing of tense reported for Indo-European languages? This question was also addressed in the study in Chapter 4 of this dissertation.

Using ERPs, the findings of this study showed both commonalities and differences regarding the brain responses to temporal violations, between Indo European languages, synthetic languages (such as Chinese that uses aspectual adverbs), and Akan. In terms of commonalities, the results of our study revealed that temporal disagreement in Akan elicited a P600-like ERP component, although this effect was found only in violations of the present time frame by a past verb form, and not evident when a past time frame was violated by a present verb form. Previous studies on temporal (dis)agreement in Indo European languages have demonstrated a centro-posterior positivity P600 brain response to tense violations, in some studies a left anterior negativity (LAN: peaking around 300–500 ms after the onset of the verb) preceding the P600 (English: Steinhauer & Ullman, 2002; Dutch: Baggio, 2008). Interestingly, in so-called tenseless languages, in which temporal reference is marked by aspectual adverbs, like Chinese (Qiu & Zhou, 2012) and Thai (Siriboonpipattana et al., submitted), a P600 (together with an N400) has also been elicited in temporal violations. This has resulted in the P600 being the most consistent and sensitive component to time reference violations in all languages investigated, regardless of the form in which time reference is expressed – whether through bound morphemes, free-standing morphemes or grammatical tone, as in the case of Akan.

However, the uniqueness of grammatical tone was reflected in the nature of the P600 elicited. First, the P600 observed in this study was longer-lasting (until around 1200 ms) than what was observed in English and Dutch (Steinhauer & Ullman, 2002; Baggio, 2008, respectively). This can be associated with the differences in the verb morphology of these languages. Inflected past and present habitual verbs in Akan (e.g. past: pèpàà 'mopped'; present habitual: pèpá 'mops') have two points of inflection: 1) the duration of the first syllabic tone, and 2) the duration and height of the second syllabic tone. That is, the past and the present habitual do not only differ (in height and duration) at the last syllable but also (in duration) at the first syllable. Although this finding is novel (because Akan is an understudied language), we suggest that the inflection on the first syllable is due to an assimilation process resulting from either a prolonged or short tonal duration of the following syllable. In contrast, Indo-European languages such as English (see Steinhauer & Ullman, 2002), have only one verb inflection point, always at the end of the verb. Therefore, while in Akan, the parser recognizes two disambiguation points when processing adverb-verb disagreement, in Indo-European languages, there is only one point of disambiguation which the parser recognizes only at the end of the verb (Dutch: Baggio, 2008; Dragoy et al., 2012; English: Steinhauer & Ullman, 2002). Furthermore, these differences can also be explained by the differences in experimental presentation modalities. While sentences were presented in a reading paradigm in the previous studies, the current study used a listening paradigm. Since the brain responses elicited by written and spoken sentences are not identical brain responses (Popov, 2017), it is likely that the observed effect in our study was influenced by the paradigm used.

Secondly, the scalp distribution of the P600 differs from that found in other languages. The topographic maps of the P600 effect in this study showed a fronto-central distribution, as opposed to the centro-posterior P600 effect observed in Indo-European languages (Baggio, 2008; Dragoy et al., 2012; Steinhauer & Ullman, 2002, but see Siriboonpipattana et al., submitted for a fronto-central distribution in Thai). These distributional differences can be associated with the differences in the type of violations used in these studies. While the temporal violations used in previous studies in Indo-European languages were ungrammatical in nature, those used in Akan, particularly the past violations, could be considered as 'non-preferred' (see Friederici et al. 2002; Kaan & Swaab, 2003) rather than ungrammatical. Kaan and Swaab (2003) reported that non-preferred (e.g. garden path) sentences elicit a late P600 effect distributed fronto-centrally, indicating ambiguity resolution, whereas ungrammatical sentences give rise to a posterior P600 effect, indicating a pure (morpho-)syntactic violations.

In summary, there are both commonalities and differences in processing temporal relations across languages. The differences mainly arise as a result of the typological differences between these languages.

5.2. CLINICAL AND RESEARCH RELEVANCE OF THE RESULTS OF THIS PROJECT

Akan is a language which has been barely explored, as far as clinical linguistics research is concerned. The research findings outlined in this dissertation instigates the need for more clinical linguistics research as well as the development of language tests for diagnosis and treatments not only for speakers with agrammatic aphasia but also individuals with other neurological pathologies, in the Ghanaian clinical setting. One of the important findings is that both individuals with left and right hemisphere brain damage showed impairments in their ability to perceive grammatical tone, which is one of the crucial elements in Akan sentence structure. Since Akan is a tonal language, an impairment in tonal perception might underlay potential problems individuals with right hemisphere damage may have in other aspects of language processing. Therefore, it is to be recommended that tonal processing abilities are factored in when developing assessment tools and new materials for language disorders diagnosis and therapy in Ghana.

Another finding with practical implications is that for Akan individuals with agrammatic aphasia, time reference, particularly to the past is likely to be impaired. The results demonstrated that the problems with expressing past time reference are not restricted to verb inflection per se, but rather affect the entire notion of past, because it requires discourse linking (Bastiaanse, 2013). This was supported by the electrophysiological data, which showed that even for individuals without brain damage, there are different brain mechanism involved in past and non-past processing. This knowledge is crucial, and should be taken into account when developing treatment materials for aphasia therapy in Ghana.

As far as linguistic research is concerned, this project also re-emphasizes the need for cross-linguistic studies, especially in understudied languages, in order to test and broaden the already existing linguistic theories. Africa alone boasts of having over 1000 tonal languages which have typologically unique characteristics (Gandour, 1998, 2006), and yet the majority of the neuro- and psycholinguistic theories have been built on Asian tonal languages, such as Mandarin and Cantonese Chinese, and Thai. This research asymmetry poses a challenge for formulating theories that can be readily generalized to African tonal languages. For example, in Chapter 3 of this dissertation, it was shown that neither of the two prominent theories on hemispheric lateralization of tone perception could account for the perception of grammatical tone (which does not exist in Asian tonal languages) in Akan speakers with right and left hemisphere brain damage. Nonetheless, the findings of this project also strengthen some of the already existing neurolinguistic theories. For instance, the findings of the first study showed that past time reference was more difficult than non-past time reference for agrammatic speakers of a language that uses grammatical tone, rather than affixes to make time reference. This finding strengthens the claims of the Past Discourse Linking Hypothesis (PADILIH: Bastiaanse, 2013) which had been previously tested mostly in languages that use grammatical affixes and aspectual adverbs for time reference. In sum, the findings of this project contribute to some of the ongoing discussions in neuro/psycholinguistic research.

5.3. SCOPE FOR FUTURE RESEARCH

The studies and analyses presented in this dissertation provide numerous directions for future research on tone and time reference processing. To begin with, we have barely scratched the surface of tone processing in Akan. The studies in this dissertation predominantly focused on grammatical tone processing using Akan verbs. However, Akan also has lexical tone (e.g. *pàpá* 'father'; *pàpà* 'fan'), and, thus, future studies may consider a systematic comparison between lexical and grammatical tone processing in one experimental paradigm, in the same language, and with the same participants. This will give more insight into the distinct mechanism(s) that underlie tone processing both at the word and sentence level. Obviously, one of the limitations of the clinical studies in this dissertation was the limited sample size. Therefore, future studies should aim to have bigger sample sizes to be able to draw more stronger conclusions. It would be interesting for such a study to also consider exploring individuals with neurodegenerative diseases such as Alzheimer's Disease, Parkinson's Disease or Primary Progressive Aphasia, since these groups have also been shown to have language impairments. Another possibility to advance future research is to re-examine or complement the findings of the current studies by using the written modality as compared to the auditory modality used in all three studies in this dissertation. Since both grammatical and lexical tones in Akan are not represented orthographically, such a study should have a paradigm in which a context would prime the elicitation of either grammatical or lexical tone. Lastly, since the Akan agrammatic speakers showed a dissociation between future and present habitual time references, it would be interesting to examine if this dissociation would also be present in an event related potentials (ERPs) study.

Summary

The goal of this thesis was to understand how the distinctive realization of Akan verb morphology – comprising grammatical tone and time reference, is processed in the brain, and how this relates to what has been discovered in other languages. This was addressed by investigating Akan brain damaged speakers with and without aphasia, as well as non-brain damaged Akan speakers, using behavioral and neurophysiological methods.

Chapter 1, which contains the general introduction of this thesis, provided the theoretical framework for time reference and tone processing in brain damaged individuals with and without aphasia. The *Past Discourse Linking Hypothesis* (henceforth PADILIH) which captures the past time reference deficit in agrammatic aphasia was delineated. This was followed by a description of the Akan language and its tonal inventories – grammatical and lexical functions of tone. The theoretical background of studies that have investigated lexical tone processing in other languages was also outlined. The purpose of the current thesis, as well as the research questions were also defined. Finally, the outline of the entire thesis was provided.

Chapter 2 presented a study on grammatical tone processing in individuals with left (LHD) and right (RHD) hemisphere brain damage. The aim of this study was twofold: Firstly, to examine how individuals with LHD and RHD perceive grammatical tone, and how this compares to lexical tone perception in other languages. The second aim was to compare grammatical tone to non-linguistic tone perception. Therefore, native Akan speakers with LHD, RHD and no-brain damage (NBD) controls were tested in two discrimination tasks that examined linguistic (grammatical) and non-linguistic tone perception. The results showed that both the individuals with LHD and RHD show impairment in grammatical tone perception. Comparatively, this result is consistent with clinical data for lexical tone perception in other tonal languages: both individuals with left and right hemisphere brain damage show impairments in lexical tone perception (Norwegian: Moen & Sundet 1996; Thai: Gandour & Dardarananda, 1983; Gandour et al., 1992; Shona: Kadyamusuma et al., 2011a). Surprisingly, problems with grammatical tone perception were equally pronounced in individuals with left and right hemisphere

damage, and this is not in line with the findings of previous studies on lexical tone showing an asymmetric performance. However, for the results on non-linguistic tone perception, individuals with LHD outperformed the RHD individuals, although both had reduced performance compared to the individuals NBD. We conclude that there is potentially a bilateral involvement of the two hemispheres in grammatical tone processing, with the left being the dominant hemisphere.

Chapter 3 aimed to examine whether past time reference deficit, which has been found in languages that use grammatical affixes for time reference, can also be observed in Akan, which uses grammatical tone to make time reference. Secondly, this study aimed to disentangle the effect of tone from the effect of temporal reference on Akan verbs. Ten Akan agrammatic speakers and ten non-brain-damaged speakers were tested with an Akan adapted version of the Test for Assessing Reference of Time (African TART: Abuom and Bastiaanse, 2010), in the form of a sentence completion (production) and a sentence-picture-matching (comprehension) task. The TART focuses on the future, present (habitual) and the past time frames. Additionally, five of the agrammatic speakers performed two tonal discrimination tasks: a non-linguistic and a linguistic (lexical) one. The results showed that in both production and comprehension, verb forms referring to the past were more problematic for the Akan agrammatic speakers than verb forms referring to either present habitual or future. The comprehension data, however, indicated a dissociation between the present habitual and the future, with the latter being more affected, although both were relatively preserved in production. Moreover, the error analysis revealed that there was a preference for present habitual verb forms whenever there were substitution errors. The non-linguistic tone task demonstrated that tone per se is relatively preserved in Akan speakers with agrammatic aphasia. Therefore, we conclude that for individuals with agrammatic aphasia, regardless of how time reference is expressed – whether through inflectional morphology or grammatical tone, reference to the past is more problematic than non-past time reference. This is because past time reference requires discourse linking, whereas the non-past time reference do not. Additionally, the fact that the agrammatic speakers could perceive the non-linguistic tonal differences indicates that it is not tone in general that is disrupted, but rather time reference, particularly reference to the past, as predicted by the PADILIH.

In Chapter 4, the electrophysiological processing of temporal relations in healthy Akan speakers was examined. The study presented in this chapter sought to answer two questions: Firstly, does the neural processing of temporal agreement in grammatical tone languages follow the patterns found in languages (such as the Indo-European group) in which temporal reference is expressed through inflectional morphology, that is, through affixes? The second question was: Do the brain responses for past and present habitual time violations differ in a grammatical tone language? To address these questions, twenty-four native speakers of Akan listened to sentences with time reference violations (mismatch between temporal adverb and verb), and their brain responses were recorded using electroencephalography (EEG). Our results indicated that a violation of a present context by a past verb yields a P600 (indicative of sentence reanalysis/repair) time-locked to the verb. This result shows both commonalities and differences regarding the brain responses to temporal violations, between Indo European languages and Akan. That is, while the elicitation of the P600 demonstrate similar cognitive underpinnings for temporal violation processing in both Akan and Indo-European languages, the topographic and the longer lasting nature of the P600 seems to portray the typological differences between these languages. Interestingly, there was no P600 effect when a past context was violated by a present verb, suggesting that the processing of present habitual and past verb forms in Akan involve different neuronal processes. This is consistent with the dissociation found between the past and the present (habitual) among Akan agrammatic aphasic speakers, as presented in Chapter 3.

Chapter 5 provided a conclusion to the dissertation by delineating a general discussion for the major findings of each of the three studies (comprising Chapters 2, 3 and 4), and the overall clinical implications of these findings. It has been demonstrated in this thesis that grammatical tone processing is problematic for individuals with brain damage. However, the problems with grammatical tone processing, particularly in individuals with brain damage leading to agrammatic aphasia, may have been largely driven by past time reference deficit, and not necessarily grammatical tone per se. This is because past time reference requires extra processing load compared to the non-past time reference. The dissociation between the past and non-past processing was also confirmed by the electrophysiological brain response of non-brain damaged Akan speakers. These findings outlined in the current dissertation instigates the need for more clinical linguistics research as well as the development of language tests for diagnosis and treatments for Akan speakers with language pathologies, particularly for speakers with agrammatic aphasia. Chapter 5 concluded with recommendations for future research.

Samenvatting

Het doel van dit proefschrift was om te begrijpen hoe de distinctieve realisatie van Akanse werkwoordmorfologie – dat grammaticale toon en tijdsverwijzing bevat, verwerkt wordt in de hersenen, en hoe dit relateert aan wat hierover gevonden is in andere talen. Dit werd onderzocht met gedrags- en neurofysiologische methoden bij Akan sprekers met hersenletsel, met en zonder afasie, en bij Akan sprekers zonder hersenletsel.

Hoofdstuk 1, dat de algemene introductie van dit proefschrift omvat, levert het theoretisch kader voor tijdsverwijzing en toonverwerking bij mensen met hersenletsel, met en zonder afasie. De *Past Discourse Linking Hypothesis* (voortaan PADILIH) werd uitgelegd, die betrekking heeft op verstoorde tijdsverwijzing naar het verleden bij agrammatische afasie. Dit werd gevolgd door een beschrijving van de Akanse taal en haar tooneigenschappen – grammaticale en lexicale functies van toon. Ook werd de theoretische achtergrond geschetst van studies die lexicale toonverwerking in andere talen onderzocht hebben. Het doel van het onderhavige proefschrift en de onderzoeksvragen werden gedefinieerd. Ten slotte werd een overzicht van het gehele proefschrift gegeven.

Hoofdstuk 2 presenteerde een studie over grammaticale toonverwerking bij mensen met hersenletsel in de linker (LHD) en rechter hemisfeer (RHD). Het doel van deze studie was tweeledig. Ten eerste onderzocht het hoe mensen met LHD en RHD grammaticale toon waarnemen, en hoe dit zich verhoudt tot lexicale toonperceptie in andere talen. Het tweede doel was het vergelijken van grammaticale toonperceptie met niet-linguïstische toonperceptie. Daarom werden moedertaalsprekers van Akan met LHD, met RHD, en zonder hersenletsel (NBD), getest met twee discriminatietaken die linguïstische (grammaticale) en niet-linguïstische toonperceptie onderzochten. De resultaten lieten zien dat zowel mensen met LHD als mensen met RHD een verstoorde grammaticale toonperceptie hebben. Naar verhouding is dit resultaat consistent met de klinische data van lexicale toonperceptie in andere toontalen: mensen met hersenletsel in de linker en rechter hemisfeer vertonen beiden een verstoorde lexicale toonperceptie (Noors: Moen & Sundet 1996; Thais: Gandour & Dardarananda, 1983; Gandour et al., 1992; Shona: Kadyamusuma et al., 2011a). Het was verrassend dat problemen met grammaticale toonperceptie vergelijkbaar voorkwamen bij mensen met hersenletsel in de linker en rechter hemisfeer. Dit is niet in lijn met de bevindingen van eerdere studies over lexicale toon, die een asymmetrisch patroon lieten zien. Echter, in de resultaten van niet-linguïstische toonperceptie presteerden mensen met LHD beter dan mensen met RHD, ook al hadden beide groepen een verminderde prestatie vergeleken met mensen zonder hersenletsel. We concludeerden dat er potentieel een bilaterale betrokkenheid van de twee hemisferen in grammaticale toonverwerking bestaat, met de linker als de dominante hemisfeer.

Hoofdstuk 3 was gericht op het onderzoeken of verstoorde tijdsverwijzing naar het verleden, dat gevonden werd in talen die grammaticale affixen voor tijdsverwijzing gebruiken, ook gezien kan worden in Akan, dat grammaticale toon gebruikt voor tijdsverwijzing. Ten tweede had deze studie als doel om het effect van toon en het effect van temporele verwijzing op Akanse werkwoorden te ontrafelen. Tien agrammatische Akan sprekers en tien Akan sprekers zonder hersenletsel werden getest met een aangepaste Akanse versie van de *Test for Assessing Reference of Time* (Afrikaanse TART: Abuom and Bastiaanse, 2010) in de vorm van een zinsaanvultaak (productie) en een zin-afbeelding-matchingstaak (begrip). De TART richt zich op toekomstige, (onvoltooid) tegenwoordige en verleden tijdskaders. Daarnaast voerden vijf van de agrammatische sprekers twee toondiscriminatietaken uit: een niet-linguïstische en een linguïstische (lexicale). De resultaten tonen dat, zowel in productie als in begrip, werkwoordsvormen die verwijzen naar het verleden problematischer zijn voor agrammatische Akan sprekers dan werkwoordsvormen die verwijzen naar het heden of de toekomst. De begripsdata duiden echter op een dissociatie tussen het heden en de toekomst, waarin de laatstgenoemde het meest aangedaan was, hoewel de twee relatief intact waren bij productie. Bovendien onthulde de foutenanalyse dat er een voorkeur bestond voor werkwoordsvormen in de onvoltooid tegenwoordige tijd wanneer er substitutiefouten waren. De niet-linguïstische toontaak liet zien dat toon op zichzelf relatief intact is bij Akan sprekers met agrammatische afasie. Daarom concluderen we dat verwijzing naar het verleden problematischer is dan verwijzing naar het niet-verleden voor mensen met agrammatische afasie, ongeacht hoe tijdsverwijzing uitgedrukt wordt – door middel van inflectionele morfologie of grammaticale toon. Dit komt doordat verwijzing naar het verleden een 'discourse-link' vereist, terwijl dit niet het geval is bij verwijzing naar het niet-verleden. Ook het feit dat de agrammatische sprekers de niet-linguïstische toonverschillen kunnen onderscheiden, geeft aan dat toon op zichzelf niet verstoord is. Tijdsverwijzing is verstoord en in het bijzonder verwijzing naar het verleden, zoals voorspeld door de PADILIH.

In hoofdstuk 4 werd de elektrofysiologische verwerking van temporele relaties onderzocht bij gezonde Akan sprekers. De studie in dit hoofdstuk streefde ernaar twee vragen te beantwoorden. Ten eerste: volgt de neurale verwerking van temporele congruentie in grammaticale toontalen de patronen die gevonden zijn in talen (zoals de Indo-Europese groep), waarbij temporele verwijzing uitgedrukt wordt via inflectionele morfologie, namelijk via affixen? De tweede vraag was: verschillen de hersenresponsen van verleden tijdsschendingen en onvoltooid tegenwoordige tijdsschendingen in een grammaticale toontaal? Om deze vragen te bestuderen, luisterden vierentwintig moedertaalsprekers van Akan naar zinnen met tijdsverwijzingsschendingen (incongruentie tussen temporeel bijwoord en werkwoord), en werden hun hersenresponsen opgenomen door middel van elektro-encefalografie (EEG). Onze resultaten toonden dat een schending van een tegenwoordige context door een werkwoord in de verleden tijd een P600 teweegbrengt (indicatief voor heranalyse/herstel van de zin), dat tijdsgebonden is met het werkwoord. Dit resultaat laat zowel overeenkomsten als verschillen zien met betrekking tot de hersenresponsen van temporele schendingen tussen Indo-Europese talen en Akan. Terwijl het teweegbrengen van de P600 een vergelijkbare cognitieve grondslag aantoont voor de verwerking van temporele schendingen in zowel Akan als Indo-Europese talen, lijkt de topografische en langer aanhoudende aard van de P600 de typologische verschillen tussen deze talen te illustreren. Interessant genoeg trad er geen P600 effect op wanneer een verleden context werd geschonden door een werkwoord in de tegenwoordige tijd. Het suggereert dat de verwerking van werkwoordsvormen in de onvoltooid tegenwoordige tijd en de verwerking van werkwoordsvormen in de verleden tijd in Akan verschillende neurale processen beslaan. Dit is consistent met de dissociatie die gevonden werd tussen het verleden en het heden bij Akan sprekers met agrammatische afasie, zoals beschreven in hoofdstuk 3.

Hoofdstuk 5 geeft een conclusie van de dissertatie door een algemene discussie uiteen te zetten met de belangrijkste bevindingen van elk van de drie studies (bestaande uit hoofdstuk 2, 3 en 4) en de globale klinische implicaties van deze bevindingen. Dit proefschrift heeft aangetoond dat grammaticale toonverwerking problematisch is voor mensen met hersenletsel. Desondanks kunnen de problemen met grammaticale toonverwerking, in het bijzonder bij mensen met hersenletsel dat leidde tot agrammatische afasie, grotendeels gedreven zijn door verstoorde verwijzing naar het verleden en niet noodzakelijkerwijs door grammaticale toon op zich. Dit komt doordat verwijzing naar het verleden extra verwerkingsbelasting vereist, vergeleken met verwijzing naar het niet-verleden. De dissociatie in de verwerking van het verleden versus het niet-verleden werd ook bevestigd door de elektrofysiologische hersenresponsen van Akan sprekers zonder hersenletsel. De bevindingen die beschreven staan in deze dissertatie benadrukken de noodzaak voor meer klinisch linguïstisch onderzoek, evenals de ontwikkeling van taaltests voor de diagnose en behandeling van Akan sprekers met taalstoornissen, met name voor sprekers met agrammatische afasie. Hoofdstuk 5 sluit af met aanbevelingen voor toekomstig onderzoek.

Appendices

Appendix to Chapter 2: Perception of grammatical tone in Akan patients with left and right hemisphere brain damage

Appendix 2-1. Demographic data for the clinical group and the none-brain-damaged speakers

Participants	Age	Gender	Handedness	Education (years)	Months PO	Etiology/Lesion site	Hemiplegia
Agrammatic speakers							
LHD1	69	M	Right	13	24	CVA Left temporo-parietal	none
LHD2	37	M	Right	16	7	Left fronto-parietal infarct	right
LHD3	19	F	Right	12	7	iCVA Acute left-fronto-parietal-occipital infarct	right
LHD4	49	M	Right	10	25	CVA Left middle cerebral artery	none
LHD5	76	F	Right	16	12	hCVA left	right
LHD6	67	F	Right	10	7	hCVA left	right
RHD1	53	M	Right	12	3	hCVA right temporoparietal	left
RHD2	34	M	Right	9	3	Acute right temporoparietal	left
RHD3	40	F	Right	10	36	hCVA right	left
RHD4	61	M	Right	12	5	hCVA right	left
RHD5	67	M	Ambidex	12	24	Right left middle cerebral artery	left
RHD6	63	M	Right	18	29	CVA right temporo-occipital region	none
Non-brain-damaged participants							
NBD1	45	F	Right	9			
NBD2	35	F	Right	9			
NBD3	52	F	Right	16			
NBD4	44	M	Right	16			
NBD5	71	F	Right	16			
NBD6	37	M	Right	12			
NBD7	63	M	Right	16			
NBD8	48	M	Right	16			
NBD9	58	M	Right	12			
NBD10	58	F	Right	9			

Appendix 2-2. GLMER output of the groups' performance on LT and NON-LT.

(Intercept: Task = Non-LT, Group = LHD)	**2.75**	**0.364**	**7.55**	$p <$ **0.001***
GroupNBD	4.80	1.463	3.28	$p < 0.001$***
GroupRHD	-1.280	0.415	-3.087	$p = 0.002$**
TaskLT	-2.305	0.426	-5.418	$p < 0.001$***
GroupNBD: TaskLT	0.763	1.056	-0.723	$p = 0.470$
GroupRHD: TaskLT	1.711	0.445	-3.842	$p < 0.001$***

Note: Non-LT = Non-Linguistic task; LT = Linguistic task; LHD = left hemisphere damage; RHD = right hemisphere damage. The glmer output was from the model that included an interaction between Group and Task as well as random intercept for Participant and Items:

Mod<-glmer(Score ~ Group * Task + (1|Participant) + (1 + Group|Item), data)

Appendix to Chapter 3: Processing of time reference in agrammatic speakers of Akan: a language with grammatical tone

Appendix 3-1. Demographic data of the agrammatic speakers and the none-brain-damaged speakers

Participants	Age	Gender	Handedness	Education (years)	Months PO	Etiology/Lesion site	Hemiplegia	BDAE Scores (%)
Agrammatic speakers								
P1	69	M	Right	13	24	CVA Left temporo-parietal	none	91
P2	37	M	Right	16	7	Left fronto-parietal infarct	right	96
P3	19	F	Right	12	7	iCVA Acute left-fronto-parietal-occipital infarct	Right	100
P4	49	M	Right	10	25	CVA Left middle cerebral artery	none	100
P5	76	F	Right	16	12	hCVA left	Right	98
P6	56	M	Right	12	24	CVA left	Right	100
P7	61	M	Right	16	36	hCVA left	Right	94
P8	55	M	Right	12	15	hCVA left	Right	100
P9	50	M	Right	16	28	iCVA left	Right	-
P10	67	F	Right	10	7	hCVA left	Right	96
Non-brain-damaged participants								
NBD1	45	F	Right	9				
NBD2	35	F	Right	9				
NBD3	52	F	Right	16				
NBD4	44	M	Right	16				
NBD5	71	F	Right	16				
NBD6	37	M	Right	12				
NBD7	63	M	Right	16				
NBD8	48	M	Right	16				
NBD9	58	M	Right	12				
NBD10	58	F	Right	9				

Appendix 3-2. Verb pairs used in the Akan-TART

Verbs in Akan	Translation	Verbs in Akan	Translation
Examples			
susu	to measure	twitwa	to cut
Test items			
kan	to read	twerɛ	to write
di	to eat	hwane	to peel
pia	to push	twe	to pull
pepa	to mop	pra	to sweep
pam	to sew	wene	to knit
sensen	to sharpen	bu	to break
nom	to drink	hwie	to pour
to	to iron	bobɔ	to fold

Appendix 3-3. Percentage of individual scores consisting of 16 items per each time frame

	Past (%)	Habitual (%)	Future (%)
Comprehension-TART			
P1	19	94	38
P2	56	88	56
P3	19	100	63
P4	13	94	50
P5	25	94	75
P6	44	88	88
P7	62	94	69
P8	6	88	81
P9	19	94	63
P10	25	94	56
Mean	29	92	64
Production-TART			
P1	56	81	94
P2	38	81	38
P3	-	-	-
P4	56	81	100
P5	-	-	-
P6	50	88	100
P7	50	88	100
P8	75	50	94
P9	69	94	94
P10	-	-	-
Mean	56	80	88

Appendix 3-4. Generalized linear mixed model output on the Akan agrammatic speakers' accuracy.

GLMER output				
Term	**β**	**Standard error**	***z*-Value**	***p*-Value**
(Intercept: Condition = Fut, Task = Comp)	0.6292	0.2852	2.206	$p = 0.0274$*
Condition=PresHab	1.9766	0.4336	4.559	$p < 0.001$***
Condition=Past	-1.5779	0.3594	-4.391	$p < 0.001$***
Task=Prod	1.5942	0.3700	4.309	$p < 0.001$***
ConditionPresHab:TaskProd	-2.6619	0.5376	-4.951	$p < 0.001$***
ConditionPast:TaskProd	-0.4461	0.4570	-0.976	$p = 0.3290$
Post-Hoc Analysis: Multiple Comparisons of Means (Tukey Contrasts)				
PresHab.Comp - Fut.Comp	1.9766	0.4336	4.559	$p < 0.001$***
Past.Comp - Fut.Comp	-1.5779	0.3594	-4.391	$p < 0.001$***
Past.Comp - PresHab.Comp	-3.5545	0.4412	-8.056	$p < 0.001$***
PresHab.Prod - Fut.Prod	-0.6853	0.4884	-1.403	$p = 0.7115$
Past.Prod - Fut.Prod	-2.0240	0.4661	-4.343	$p < 0.001$***
Past.Prod - PresHab.Prod	-1.3387	0.4315	-3.102	$p = 0.0223$

Note: Fut = Future; Comp = Comprehension; PresHab = Present Habitual; Prod = Production.

The glmer output was from the model that included an interaction between Task and Condition as well as random slopes for Condition per Participant and random effect for Items:

Mod<-glmer(Correct~Condition*Task +(1+Condition|Participant) + (1|Item), data)

Appendices to Chapter 4: Online processing of temporal agreement in a grammatical tone language: An ERP study

Appendix 4-1: Figure 1

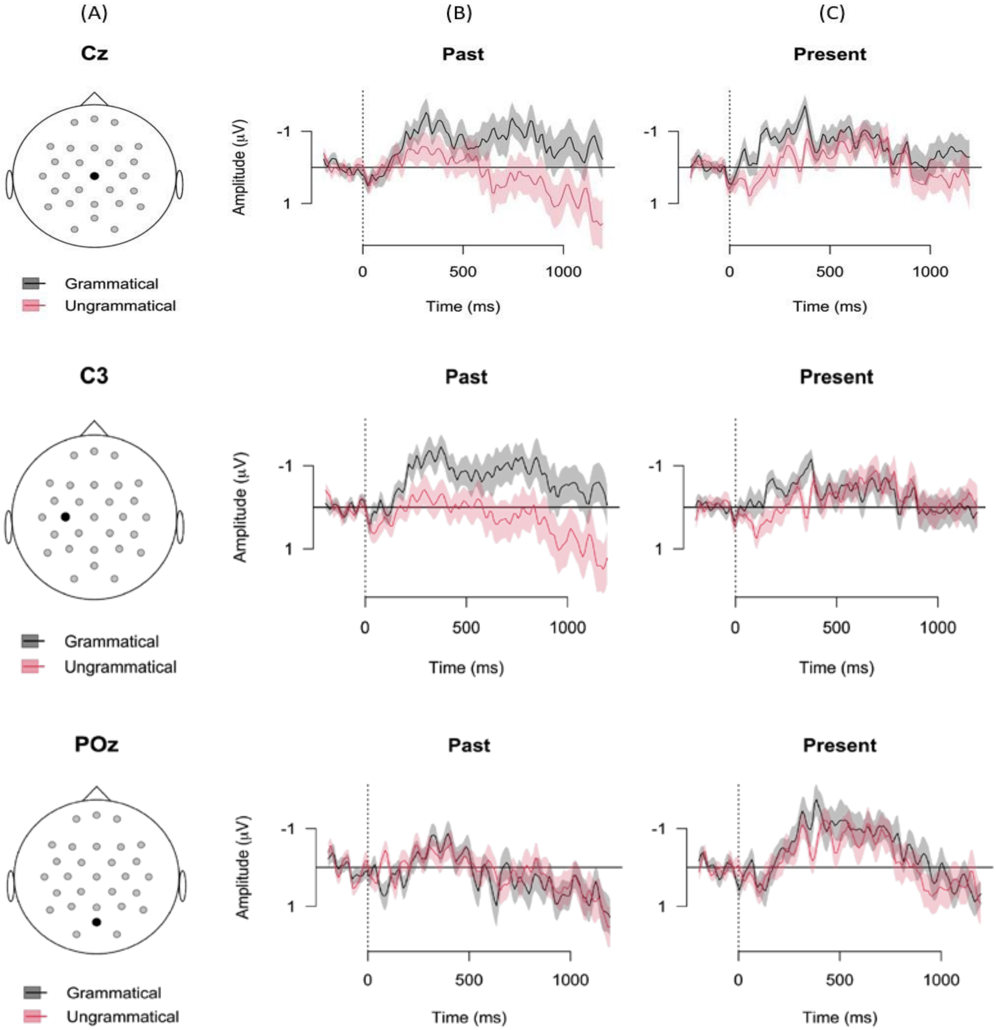

Figure 1. Data: Grand averages of the electrodes C3, Cz, and POz (error bars: ±1 SE, based on participant means). The x-axes show the time (in ms) from verb onset, and the y-axes show the grand means of the recorded amplitudes (negative upward). (A): Electrode position. (B): Grand averages of the grammatical past tense sentences (black line) and the ungrammatical past tense sentences (red line). (C): Grand averages of the grammatical present tense sentences (black line) and the ungrammatical present tense sentences (red line).

A

Appendix 4-2: Figure 2

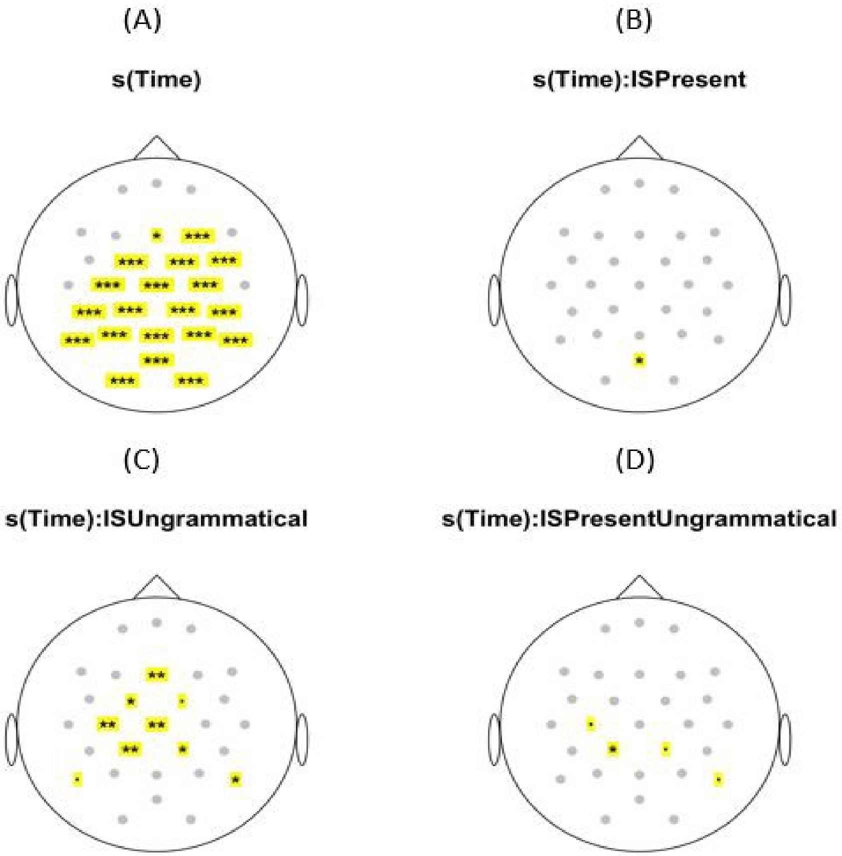

Figure 2. Summary Statistics: Overview of summary statistics of nonlinear fixed-effects. Each GAMM modelled the interaction between Time, Verb form, and Grammaticality with four nonlinear terms: s(Time) + s(Time, by=ISPresent) + s(Time, by=ISUngrammatical) + s(Time, by=ISPresentUngrammatical). Each panel below shows the summary statistics for one term in each GAMM.

(A): Summary statistics for s(Time), representing the time course of the reference level Past Grammatical. Significance here means that the time course is somewhere in the time window significantly different from an amplitude of 0.

(B): Summary statistics for s(Time, by=ISPresent), representing the difference between Past Grammatical (reference level) and Present Grammatical. Significance here means that the difference between these conditions is significant somewhere in the time window.

(C): Summary statistics for s(Time, by=ISUngrammatical), representing the difference between Past Grammatical (reference level) and Past Ungrammatical. Significance here means that the difference between these conditions is significant somewhere in the time window.

(D): Summary statistics for s(Time, by=ISPresentUngrammatical), representing the additive difference between the difference between Present Grammatical and Present Ungrammatical in comparison to the difference between Past Grammatical and Past Ungrammatical. Significance here means that the difference between these differences is significant somewhere in the time window.

Signif. codes: '***' = p<0.001; '**' = p<0.01; '*' = p<0.05; '.' = p<0.1.

Appendix 4-3: Figure 3

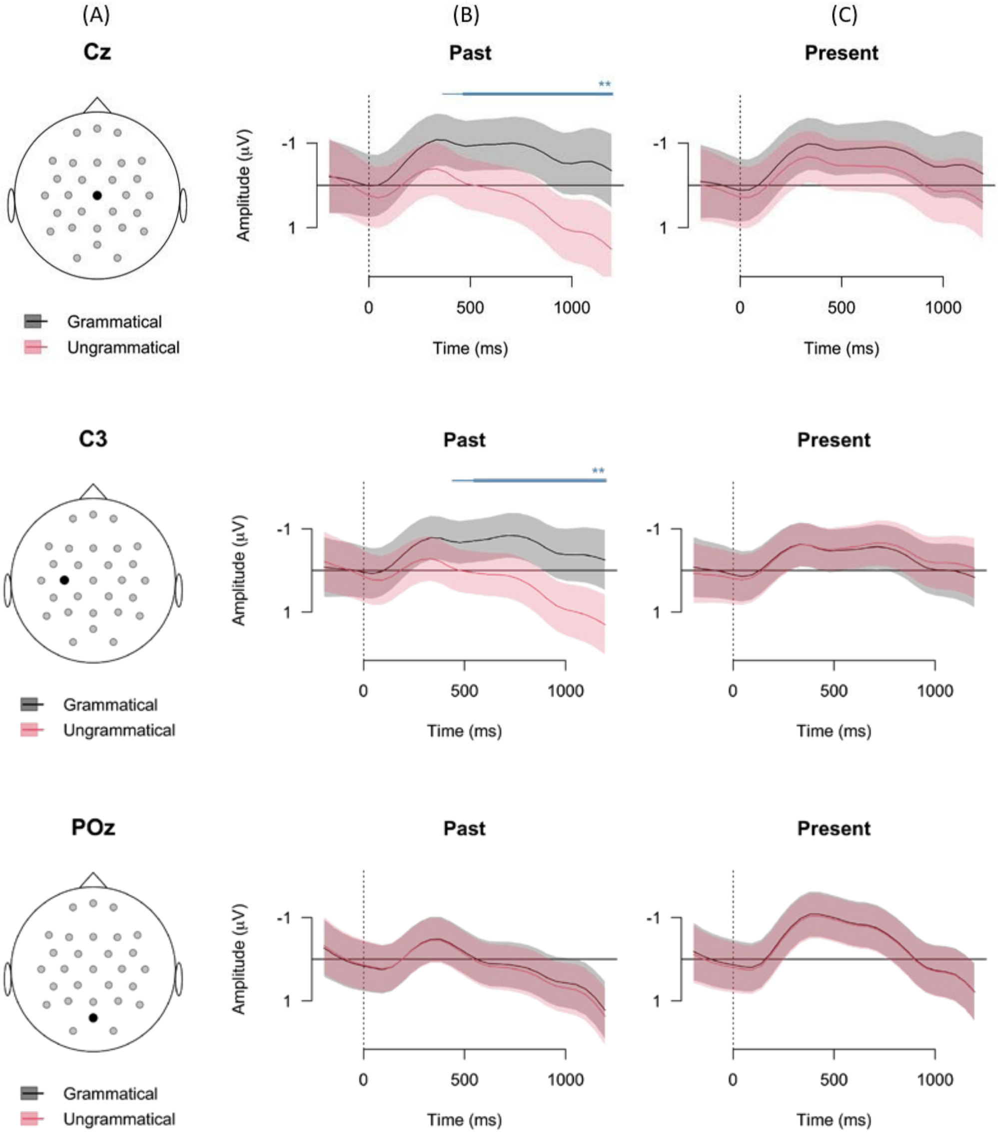

Figure 3. Model Estimates: Model estimates of the electrodes C3, Cz, and POz (error bars: ±1 SE, based on participant means). The x-axes show the time (in ms) from verb onset, and the y-axes show the grand means of the recorded amplitudes (negative upward). (A): Electrode position. (B): Model estimates of the grammatical past tense sentences (black line) and the ungrammatical past tense sentences (red line). (C): Model estimates of the grammatical present tense sentences (black line) and the ungrammatical present tense sentences (red line).

References

Abakah, E. N. (2000). A closer look at downstep in Akan. *Afrika und Übersee, 83*, 1–23.

Abakah, E. N. (2005). Tone rules in Akan. *Journal of West African Languages, XXXII*, 109–134.

Abuom, T. & Bastiaanse, R. (2010). *Test for assessing reference of time (TART): Bilingual Swahili–English version*. Groningen: University of Groningen.

Abuom, T., Obler, L. & Bastiaanse, R. (2011). Using Swahili and English to test explanations of agrammatism. *Aphasiology, 25*, 559-576.

Anjarningsih, H. Y. & Bastiaanse, R. (2011). Verbs and time reference in Standard Indonesian agrammatic speech. *Aphasiology, 25*, 1562–1578.

Abuom, T. & Bastiaanse, R. (2012). Characteristics of Swahili-English bilingual agrammatic spontaneous speech and the consequences for understanding agrammatic aphasia. *Journal of Neurolinguistics, 25*, 276-293.

Abuom, T. O. & Bastiaanse, R. (2013). Production and comprehension of reference of time in Swahili-English bilingual agrammatic speakers. *Aphasiology, 27*, 157-177.

Avrutin, S. (2000). Comprehension of discourse-linked and non-discourse linked questions by children and Broca's aphasics. In Grodzinsky, Y. Shapiro, L. and Swinney, D. (Eds.), *Language and the brain*. San Diego: Academic Press.

Avrutin, S. (2006) Weak syntax. In Amunts, K. & Grodzinsky, Y. (Eds.), *Broca's Region*. (49-62). New York: Oxford Press.

Baayen, R. H., Tremblay, A., & Hendrix, P. (2015). An introduction to analyzing the ERP signal with generalized additive modeling using the gam-erp package, vignette for the GAM-ERP package for R. *Vignette and package in preparation*.

Baggio, G. (2008). Processing temporal constraints: An ERP study. *Language Learning, 58*, 35-55.

Bastiaanse, R. & Jonkers, R. (1998). Verb retrieval in action naming and spontaneous speech in agrammatic and anomic aphasic aphasia. *Aphasiology 12*, 951-969.

Bastiaanse, R. (2008) Production of verbs in base position by Dutch agrammatic speakers: Inflection versus finiteness. *Journal of Neurolinguistics, 21*, 104-119.

Bastiaanse, R., Bamyaci, E., Hsu, C.-J., Yarbay Duman, T., Lee, J. & Thompson, C.K. (2011). Time reference in agrammatic aphasia. A cross-linguistic study. *Journal of Neurolinguistics, 24*, 652-673.

Bastiaanse, R. (2013). Why reference to the past is difficult for agrammatic speakers. *Clinical Linguistics and Phonetics, 27*, 244-263.

Bates, D., Maechler, M. & Bolker, B. (2013). *Linear mixed-effects models using S4 classes*. Vienna, Austria: R Foundation for Statistical Computing. URL http://lme4.r-forge.r-project.org/

Baum, S. R. & Pell, M. D. (1997). Production of affective and linguistic production by brain-damaged patients. *Aphasiology, 11*, 177-198.

Behrens, S. J. (1989). Characterizing sentence intonation in a right hemisphere damaged population. *Brain and Language 37*, 181–200.

Blake, M. L., Duffy, J. R., Myers, P. S. & Tompkins, C. A. (2002). Prevalence and patterns of right hemisphere cognitive/communicative deficits: Retrospective data from an inpatient rehabilitation unit. *Aphasiology, 16*, 537–547.

Boadi, L. A. (2008). Tense, aspect and mood in Akan. In F. Ameka & M. E. K. Dakubu (Eds.), *Aspect and modality in Kwa Languages* (pp. 9–68). Amsterdam: John Benjamins Publishing Company.

Bos, L.S., Dragoy, O., Stowe, L.A. & Bastiaanse, R. (2013). Time reference teased apart from tense: Thinking beyond the present. *Journal of Neurolinguistics, 2*, 283–297.

Bos, L.S. & Bastiaanse, R. (2014). Time reference decoupled from tense in agrammatic and fluent aphasia. *Aphasiology, 28*, 533-553.

Brouwer, H., Fitz, H. & Hoeks, J. (2012). Getting real about semantic illusions: Rethinking the functional role of the P600 in language comprehension. *Brain Research, 1446*, 127–143, http://dx.doi.org/10.1016/j.brainres.2012.01.055.

Bruder, G.E., Wexler, B.E., Sage, M.M., Gil, R.B. and Gorman, J.M. (2004). Verbal memory in schizophrenia: additional evidence of subtypes having different cognitive deficits. *Schizophrenia Research, 68*, 137-147.

Bruder, G.E., Alschuler, D.M., Kroppmann, C.J., Fekri, S., Gil, R., Jarskog, L.F., Harkavy-Friedman, J.M., Goetz, R., Kayser, J. & Wexler, B.E. (2011). Heterogeneity of auditory verbal working memory in schizophrenia. *Journal of Abnormal Psychology, 120* ,88-97.

Burchert, F., Swoboda-Moll, M. & De Bleser, R. (2005). Tense and agreement dissociations in German agrammatic speakers: Under-specification versus hierarchy. *Brain and Language, 94*, 188–199.

Chandrasekaran B., Krishnan A. & Gandour J. T. (2007) Mismatch negativity to pitch contours is influenced by language experience. *Brain Research, 1128*, 148–156.

Chandrasekaran B., Krishnan A. & Gandour J. T. (2009). Sensory processing of linguistic pitch as reflected by the mismatch negativity. *Ear and Hearing. 30*, 552–558.

Comrie, B. (1976). *Aspect*. Cambridge: Cambridge University Press.

Comrie, B. (1985). *Tense*. Cambridge: Cambridge University Press.

Danly, M. & Shapiro, B. (1982). Speech prosody in Broca's aphasia. *Brain and Language, 16*, 171-190.

Dolphyne, F. A. (1988). *The Akan (Twi-Fante) language: Its sound systems and tonal structure*. Accra: Universities of Ghana Press.

Dragoy, O., Stowe, L. A., Bos, L. S. & Bastiaanse, R. (2012). From time to time: processing time reference violations in Dutch. *Journal of Memory and Language, 66*, 307–325.

Dragoy, O. & Bastiaanse, R. (2013). Aspects of time: Time reference and aspect production in Russian aphasic speakers. *Journal of Neurolinguistics, 26*, 113–128.

Faroqi-Shah, Y. & Thompson, C. K. (2007). Verb inflections in agrammatic aphasia: encoding of tense features. *Journal of Memory and Language, 56*, 129–151.

Faroqi-Shah, Y. & Dickey, M. W. (2009). On-line processing of tense and temporality in agrammatic aphasia. *Brain & Language, 108*, 97–111.

Faroqi-Shah, Y. & Friedman, L. (2015). Production of verb tense in agrammatic aphasia: A meta- analysis and further data. *Behavioural Neurology, 2015*, 1–15.

Frenck-Mestre, C., Meunier, C., Espesser, R., Daffner, K. & Holcomb, P. (2005). Perceiving nonnative vowels: The effect of context on perception as evidenced by event-related brain potentials. *Journal of Speech, Language, and Hearing Research, 48*, 1496 -1510.

Friederici, A. D., Hahne, A. & Saddy, D. (2002). Distinct neurophysiological patterns reflecting aspects of syntactic complexity and syntactic repair. *Journal of Psycholinguistic Research, 31*, 45–63.

Friederici, A. D. & Alter, K. (2004). Lateralization of auditory language functions: a dynamic dual pathway model. *Brain Language 89,* 267-276.

Friedmann, N. & Grodzinsky, Y. (1997). Tense and agreement in agrammatic production: Pruning the syntactic tree. *Brain and Language, 56*, 397-425.

Friedmann, N. (2002). Questions production in agrammatism; the tree pruning hypothesis. *Brain and Language, 80*, 160-187.

Fritz, J.B., Elhilali, M., David, S.V. & Shamma, S. A. (2007). Auditory attention—focusing the searchlight on sound. *Current Opinion in Neurobiology,17*, 437–455.

Fromkin, V. & Rodman, R. (1993). *An introduction to language* (5th ed.). Fort Worth, TX: Harcourt Brace College Publishers.

R

Fyndanis, V., Arcara, G., Capasso, R., Christidou, P., de Pellegrin, S., Gandolfi, M., Messinis, L., Papathanasopoulos, P., Panagea, E., Smania, N., Semenza, C. & Miceli, G. (2018a). Time reference in nonfluent and fluent aphasia: A cross-linguistic test of the PAst DIscourse LInking Hypothesis. *Clinical Linguistics and Phonetics, 32*, 823–843. Doi: 10.1080/02699206.2018.1445291

Fyndanis, V., Arfani, D., Varlokosta, S., Burgio, F., Maculan, A., Miceli, G., Arcara, G., Palla, F., Cagnin, A., Papageorgiou, S. & Semenza, C. (2018b). Morphosyntactic production in Greek- and Italian-speaking individuals with probable Alzheimer's disease: Evidence from subject-verb agreement, tense/time reference, and mood. *Aphasiology, 32*, 61–87. Doi: 10.1080/02687038.2017.1358352

Gandour, J. & Dardarananda, R. (1983). Identification of tonal contrasts in Thai aphasic patients. *Brain and Language, 18,* 98-114.

Gandour, J. T. (1983). Tone perception in Far Eastern languages. *Journal of Phonetics, 11*, 149-175.

Gandour, J. & Dardarananda, R. (1984). Voice onset time in aphasia: Thai. *Brain and Language, 23*, 177–205.

Gandour, J., Petty, S. H. & Dardarananda, R. (1988). Perception and production of tone in aphasia. *Brain and Language, 35*, 201–240.

Gandour, J., Ponglorpisit, S., Khunadorn, F., Dechongkit, S., Boongird, P., Boonklam, R. and Potisuk, S. (1992b). Lexical tones in Thai after unilateral brain damage. *Brain and Language 43*, 275-307.

Gandour, J., Ponglorpisit, S. & Dardarananda, R. (1992a). Tonal disturbances in Thai after brain damage. *Journal of Neurolinguistics, 7*, 133–145.

Gandour, J., Wong, D., Hsieh, L., Weinzapfel, B. & Hutchins, G. D. (2000). A cross-linguistic PET study of tone perception. *Journal of Cognitive Neuroscience, 12*, 207-222.

Gandour, J., Wong, D., Lowe, M., Dzemidzic, M., Satthamnuwong, N. & Tong, Y. (2002). A cross-linguistic fMRI study of spectral and temporal cues underlying phonological processing. *Journal of Cognitive Neuroscience 14,* 1076–1087. doi: 10.1162/089892902320474526

Gandour, J. (2006). Tone: Neurophonetics. In K. Brown (Ed.), *Encyclopedia of language and linguistics* (2nd ed., Vol. 12, pp. 751-760). Oxford, UK: Elsevier.

Gavarró, A. & Martínez-Ferreiro, S. (2007). Tense and Agreement Impairment in Ibero–Romance. *Journal of Psycholinguistic Research, 36*, 25–46.

Ge J., Peng G., Lyu B., Wang Y., Zhuo Y., Niu Z., Tan L. H., Leff A. P. & Gao J. H. (2015). Cross-language differences in the brain network subserving intelligible speech. *Proceedings National Academy of Sciences USA 112*: 2972– 2977.

Ghana Statistical Service. (2013). 2010 population and housing census: National analytical report. Accra, Ghana: Author. Retrieved from http://www.statsghana.gov.gh/docfiles/publications/2010_PHC_National_Analytical_Report.pdf

Goodglass, H. & Kaplan, E. (1972). *Boston Diagnostic Aphasia Examination*. Philadelphia: Lea and Febiger.

Goodglass, H., Kaplan, E. & Barresi, B. (2001). *Boston diagnostic aphasia examination* (3rd Ed.). Philadelphia, PA: Lippincott Williams & Wilkins

Grangé, P. (2003). Aspect and modality in Indonesian: *The case of sudah, telah, pernah, sempat*. A paper presented at the 7th International Symposium on Malay/Indonesian Linguistics, Nijmegen, the Netherlands.

Grangé, P. (2006). *Temps et aspect et indonésien*. Unpublished doctoral dissertation. Poitiers: Université de Poitiers.

Grodzinsky, Y. (1990) *Theoretical perspectives on language deficits*. Cambridge (MA), Cambridge University Press.

Grodzinsky, Y. (1995). A restrictive theory of agrammatic comprehension. *Brain and Language, 50*, 27–51.

Gu, F., Li, J., Wang, X., Hou, Q., Huang, Y. & Chen, L. (2012). Memory traces for tonal language words revealed by auditory event-related potentials. *Psychophysiology, 49*, 1353–1360.

Gu, F., Zhang, C., Hu, A. & Zhao, G. (2013). Left hemisphere lateralization for lexical and acoustic pitch processing in Cantonese speakers as revealed by mismatch negativity. *NeuroImage, 83*, 637-645

Hagiwara, H. (1995). The breakdown of functional categories and the economy of derivation. *Brain and Language, 50*, 92-116.

Hagoort, P., Brown, C. & Groothusen, J. (1993). The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language and Cognitive Processes, 8*, 439 – 483.

Hagoort, P., Brown, C. & Osterhout, L. (1999). The neural architecture of syntactic processing. In C. Brown & P. Hagoort (Eds.), *Neurocognition of language* (pp. 273–316). Oxford: Oxford University Press.

Hagoort, P., Wassenaar, M., & Brown, C. (2003). Syntax-related ERP-effects in Dutch. *Cognitive Brain Research, 16*, 38–50.

Hastie, T. J. & Tibshirani, R. J. (1990). *Generalized additive models*. Chapman & Hall, London.

Helwig, N.E. (2018). *eegkit package*. https://cran.r-project.org/web/packages/eegkit/eegkit.pdf

Hothorn, T., Bretz, F., Westfall, P., Heiberger, R. M. & Schuetzenmeister, A. (2013). *Simultaneous inference in general parametric models*. Vienna, Austria: R Foundation for Statistical Computing. URL http://lme4.r-forge.r-project.org/

Irish, M., Kamminga, J., Addis, D. R., Crain, S., Thornton, R., Hodges, J. R. & Piguet, O. (2016). 'Language of the past' - Exploring past tense disruption during autobiographical narration in neurodegenerative disorders. *Journal of Neuropsychology, 10*, 295–316.

Jonkers, R., Boers, J., Koopmans, F., Menninga, A. & Zoodsma, J. (2007). *(Reactie) tijd*. TABU, 36, 117–126.

Jonkers, R. & de Bruin, A. (2009). Tense processing in Broca's and Wernicke's aphasia. *Aphasiology, 23*, 1252–1265.

Kadyamusuma, M. R., De Bleser, R. & Mayer, J. (2011a). Lexical tone disruption in Shona after brain damage. *Aphasiology, 25*, 1239–1260.

Kadyamusuma, M. R., De Bleser, R. & Mayer, J. (2011b). Perceptual discrimination of Shona lexical tones and low-pass filtered speech by left and right hemisphere damaged patients. *Aphasiology, 25*, 576–592.

Kayser J (2011). *Tone Screening Test (TST),* version 1.0.3. Downloaded on [09/10/ 2017] at http://psychophysiology.cpmc.columbia.edu/software/TST.

Kertesz, A. (1982). *Western Aphasia Battery*. New York: Grune & Stratton.

Kim, A. & Osterhout, L. (2005). The independence of combinatory semantic processing: evidence from event-related potentials. *Journal of Memory and Language, 52*, 205–225.

Kimura, D. (1961). Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology, 15*, 166-171.

Kimura, D. (1964). Left-right differences in the perception of melodies. *Quartely Journal of Experimental Psychology, 16*, 335-358.

Kimura, D. (1967). Functional asymmetry of the brain in dichotic listening. *Cortex, 3*, 163–168.

Klein, W., (2009). How time is encoded. In: Klein, W., Li, P. (Eds.), *The expression of time*. Mouton de Gruyter, Berlin, pp. 39–81.

Kolk, H. H., Chwilla, D. J., van Herten, M. & Oor, P. J. (2003). Structure and limited capacity in verbal working memory: a study with event-related potentials. *Brain and Language, 85*, 1–36.

Kryuchkova, T., Tucker, B. V., Wurm, L. & Baayen, R. H. (2011). Danger and usefulness in auditory lexical processing: evidence from electroencephalography. *Brain and Language, 122*, 81– 91. doi: 10.1016/j.bandl.2012.05.005.

Kung, C., Chwilla, D.J. & Schriefers, H. (2014). The interaction of lexical tone, intonation and semantic context in on-line spoken word recognition: an ERP study on Cantonese Chinese. *Neuropsychologia 53*, 293–309. https://doi.org/10.1016/j.neuropsychologia.2013.11.020

Kutas, M. & Hillyard, S.A. (1980) Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*, 203–205.

Kwok, V. P. Y., Dan, G., Yakpo, K., Matthews, S., Fox, P. T., Li, P. & Tan, L. H. (2017). A meta-analytic study of the neural systems for auditory processing of lexical tones. *Frontiers in Human Neuroscience. 11*:375. doi: 10.3389/fnhum.2017.00375e

Langsford, S., Stephens, R. G., Dunn, J. C. & Lewis, R. L. (2019). In search of the factors behind naive sentence judgments: A state trace analysis of grammaticality and acceptability ratings. *Frontiers in Psychology Language Sciences, 10*, 2886. doi: 10.3389/fpsyg.2019.02886

Laver, J. (1994). *Principles of phonetics*. Cambridge, Cambridge University Press.

Lawrence, M. A. (2013) *ez: Easy analysis and visualization of factorial experiments*. R package version 4.2–2. Available: http://cran.r-project.org/package=ez.

Lee, J., Kwon, M., Na, H. R., Bastiaanse, R. & Thompson, C. K. (2013). Production and Comprehension of Time Reference in Korean Nonfluent Aphasia. *Communication Sciences and Disorders (Seoul, Korea), 18*, 139–151.

Liang, J. & Heuven, V. J. (2004). Evidence for separate tonal and segmental tiers in the lexical specifications of words: A case study of a brain-damaged Chinese speaker. *Brain and Language, 91*, 282–293.

Liberman, A. M. & Whalen, D. H. (2000). On the relation of speech to language. *Trends in Cognitive Sciences 4*, 187–196. doi: 10.1016/S1364-6613(00)01471-6

Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.

Luo, H., Ni, J. T., Li, Z. H., Li, X. O., Zhang, D. R., Zeng, F. G. & Chen, L. (2006). Opposite patterns of hemisphere dominance for early auditory processing of lexical tones and consonants. *Proceedings of National Academy of Sciences U.S.A. 103*, 19558–19563. doi: 10.1073/pnas.0607065104

Maiste, A. C., Wiens, A. S., Hunt, M. J., Scherg, M. & Picton, T. W. (1995). Event-related potentials and the categorical perception of speech sounds. *Ear and Hearing, 16*, 68 – 90.

Martínez-Ferreiro, S. & Bastiaanse, R. (2013). Time reference in Spanish and Catalan nonfluent aphasia. *Lingua 137*, 88-105.

Meulman, N., Wieling, M., Sprenger, S. A., Stowe, L. A. & Schmid, M. S. (2015). Age effects in L2 grammar processing as revealed by ERPs and how (not) to study them. *PLoS ONE, 10*, e0143328. https://doi.org/10.1371/journal.pone.0143328

Mfum-Mensah, O. (2005). The impact of colonial and postcolonial Ghanaian language policies on vernacular use in schools in two northern Ghanaian communities. *Comparative Education, 41*, 71-85.

Miller, E. K. & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167–212.

Moen, I. & Sundet, K. (1996). Production and perception of word tones (pitch accents) in patients with left and right hemisphere damage. *Brain and Language, 53*, 267-283.

Moen, I. (2009). Deviant prosody in patients with cortical damage. *International Journal of Speech-Language Pathology, 11*, 272–276.

Monrad-Kohn, G. H. (1947). The prosodic quality of speech and its disorders (a brief survey from a neurologist's point of view). *Acta Psychiatrica Scandinavia, 22*, 255–69

Näätänen, R. (2001). The perception of speech sounds by the human brain as reflected by the mismatch negativity (MMN) and its magnetic equivalent (MMNm). *Psychophysiology, 38*, 1– 21.

Näätänen, R., Jacobsen, T. & Winkler, I. (2005). Memory-based or afferent process in mismatch negativity (MMN): a review of the evidence. *Psychophysiology, 42*, 25–32

Näätänen, R., Paavilainen, P., Rinne, T. & Alho, K. (2007). The mismatch negativity (MMN) in basic research of central auditory processing: a review. *Clinical Neurophysiology. 118*, 2544–2590. doi: 10.1016/j.clinph.2007.04.026

Nanousi, V., Masterson, J., Druks, J. & Atkinson, M. (2006). Interpretable vs. uninterpretable features: Evidence from six Greek-speaking agrammatic patients. *Journal of Neurolinguistics 19*, 209-238.

Nestor, P. J., Graham, N. L., Fryer, T. D., Williams, G. B., Patterson, K. & Hodges, J. R. (2003). Progressive nonfluent aphasia is associated with hypometabolism centred on the left anterior insula. *Brain, 126*, 2406–2418

Neville, H., Nicol, J., Barss, A., Forster, K. & Garrett, M. (1991). Syntactically based sentence processing classes: evidence from event-related brain potentials. *Journal of Cognitive Neuroscience, 3*, 151–165.

Nixon, J. S., van Rij, J., Li, X. & Chen, Y. (2015). Cross-category phonological effects on ERP amplitude demonstrate context-specific processing during reading aloud. In: Botinis, A. (ed) ExLing 2015: *Proceedings of the International Conference of Experimental Linguistics, International Speech Communication Association*, pp. 50–53

Osam, E. K. (2003). *An introduction to the verbal and multi-verbal system of Akan*. Paper presented to the Proceedings of the Workshop on Multi-verb Constructions. Trondheim Summer School, Trondheim.

Osam, E. K. (2008). Akan as an aspectual language. In F. K. Ameka & M. E. Kropp Dakubu (Eds.), *Aspect and modality in Kwa Languages* (pp. 69–90). Amsterdam: John Benjamins Publishing Company.

Osterhout, L. & Mobley, L. A. (1995). Event-related brain potentials elicited by failure to agree. *Journal of Memory & Language, 34*, 739–773.

Packard, J. L. (1986). Tone production deficits in nonfluent aphasic Chinese speech. *Brain and Language, 29*, 212-223.

Palancar, E. & Jean-Léo, L. (2016). *Tone and Inflection: New facts under new perspectives*. Berlin: De Gruyter Mouton

Poeppel, D. (2003). The analysis of speech in different temporal integration windows: cerebral lateralization as "asymmetric sampling in time." *Speech Communication. 41*, 245–255. doi: 10.1016/S0167-6393(02)00107-3

Pollock, J. (1989). Verb movement, Universal Grammar, and the structure of IP. *Linguistic Inquiry, 20*, 365–424.

Pulvermüller, F. & Shtyrov, Y. (2006). Language outside the focus of attention: The mismatch negativity as a tool for studying higher cognitive processes. *Progress in Neurobiology, 79*, 49-71.

Qiu, Y., & Zhou, X. (2012). Processing temporal agreement in a tenseless language: An ERP study of Mandarin Chinese. *Brain Research, 1446*, 91-10

Qualtrics. (2005). *Qualtrics Software*. Provo, Utah, USA. URL https://www.qualtrics.com.

R Core Team (2013). R: *A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. URL http://www.Rproject.org/.

Reichenbach, H. (1947). *Elements of symbolic logic*. 1st Free Press paperback, 1966 ed. London: Collier-Macmillan.

Ren, G., Yang, Y. & Li, X. (2009). Early cortical processing of linguistic pitch patterns as revealed by the mismatch negativity. *Neuroscience 162*, 87–95. http://dx.doi.org/10.1016/j.neuroscience.2009.04.021.

Sidtis, J. J. & Van Lancker-Sidtis, D. (2003). A neurobehavioral approach to dysprosody. *Seminars in Speech and Language, 24*, 93–105.

Siriboonpipattana, W., Nickels, L. & Bastiaanse, R. (2020). An investigation of time reference in production and comprehension in Thai speakers with agrammatic aphasia. *Aphasiology*. Online publication. https://doi.org/10.1080/02687038.2020.1781777

Siriboonpipattana, W., Bastiaanse, R., Nickels, L., Boye, K., Sowman, P., & Popov, S., (in review). *Time reference violation in a tenseless language: An ERP study on Thai.*

Smith, S. C. & Erbaugh, M. (2005) 'Temporal interpretation in Mandarin Chinese'. *Linguistics 43*,713–756

Stavrakaki, S. & Kouvava, S. (2003). Functional categories in agrammatism: Evidence from Greek. *Brain and Language, 86*, 129–141.

Steinhauer, K. & Ullman, M.T., (2002). Consecutive ERP effects of morpho-phonology and morpho-syntax. *Brain and Language. 83*, 62–65.

R

Stevens, A. A., Donegan, N. H., Anderson, M., Goldman-Rakic, P. S. & Wexler, B. E. (2000). Verbal processing deficits in schizophrenia. *Journal of Abnormal Psychology, 109*, 461–471. doi:10.1037/0021-843X.109.3.461

Tompkins, C. A. & Flowers, C. R. (1985). Perception of emotional intonation by brain-damaged adults: The influence of task processing levels. *Journal of Speech, Language and Hearing Research, 28*, 527–538.

Tompkins, C. (2012). Rehabilitation for cognitive-communication disorders in right hemisphere brain damage. *Archives of Physical Medicine and Rehabilitation, 93*, S61–S69.

Trousseau, A. (1864). *De l'aphasie. Clinique Médicale de I'Hotel-Dieu de* Paris (5th Ed). Paris: Ballière [1877, pp. 669-729]

Tsang, Y. K., Jia, S., Huang, J. & Chen, H. C. (2011). ERP correlates of pre-attentive processing of Cantonese lexical tones: the effects of pitch contour and pitch height. *Neuroscience Letters, 487*, 268–272. doi: 10.1016/j.neulet.2010.10.035

Tsapkini, K., Jarema, G. & Kehayia, E. (2002). A morphological processing deficit in verbs but not in nouns: A case study in a highly inflected language. *Journal of Neurolinguistics, 15*, 265–288.

Tsiwah, F., Lartey, N., Amponsah, C., Martínez-Ferreiro, S., Popov, S., & Bastiaanse, R. (2020). Processing of time reference in agrammatic speakers of Akan: A language with grammatical tone. *Aphasiology*. Online publication. https://doi.org/10.1080/02687038.2020.1727835

Van Lancker, D. & Fromkin, V. (1973). Hemispheric specialization for pitch and tone: Evidence from Thai. *Journal of Phonetics, 1*, 101-109.

Van Lanker, D. (1980). Cerebral lateralisation of pitch cues in the linguistic signal. *Papers in Linguistics, 13*, 201–277.

Van Lancker, D. & Sidtis, J. (1992). The identification of affective-prosodic stimuli by left and right hemisphere damaged subjects. All errors are not created equal. *Journal of Speech, Language and Hearing Research, 35*, 963–970.

van Rij, J., Hendriks, P., van Rijn, H., Baayen, R. H. & Wood, S. N. (2019). Analyzing the time course of pupillometric data. *Trends in Hearing Science 23*, 1–22. doi: 10.1177/2331216519832483

van Rij, J., Wieling, M., Baayen, R. H. & van Rijn, H. (2017). *itsadug: Interpreting time series and autocorrelated data using GAMMs* (published on the Comprehensive R Archive Network, CRAN). Retrieved from https://cran.r-project.org/web/packages/itsadug.

Wang, Y., Behne, D. M., Jongman, A. & Sereno, J. A. (2004). The role of linguistic 148 experience in the hemispheric processing of lexical tone. *Applied Psycholinguistics 25*, 449-466.

Wang, Y., Jongman, A. & Sereno, J. A. (2001). Dichotic perception of Mandarin tones by Chinese and American listeners. *Brain and Language, 78*, 332-348.

Wenzlaff, M. & Clahsen, H. (2004). Tense and agreement in German agrammatism. *Brain and Language, 89*, 57–68.

Wenzlaff, M. & Clahsen, H. (2005). Finiteness and verb-second in German agrammatism. *Brain and Language, 92*, 33-44.

Wexler, B. E., Stevens, A. A., Bowers, A. A., Sernyak, M. J. & Goldman-Rakic, P. S. (1998). Word and tone working memory deficits in schizophrenia. *Archives of General Psychiatry, 55*, 1093–1096. doi:10.1001/archpsyc.55.12.1093

Whalen, D. H. & Liberman, A. M. (1987). Speech perception takes precedence over nonspeech perception. *Science 237*, 169–171. doi: 10.1126/science.3603014

Wieling, M. (2018). Analyzing dynamic phonetic data using generalized additive mixed modeling: A tutorial focusing on articulatory differences between L1 and L2 speakers of English. *Journal of Phonetics, 70*, 86–116.

Wong, P. (2002). Hemispheric specialization of linguistic pitch patterns. *Brain Research Bulletin, 59*, 83–95 10.1016/s0361-9230(02)00860-2

Wong, PC.M., Parsons, L.M., Martinez, M. & Diehl, R. L., (2004). The role of the insular cortex in pitch pattern perception: the effect of linguistic contexts. *Journal of Neuroscience, 24*, 9153–9160.

Wood, S.N., (2017). *Generalized Additive Models: An Introduction with R*. 2nd ed. Boca Raton, Chapman and Hall/CRC.

Xi, J., Zhang, L., Shu, H., Zhang, Y. & Li, P. (2010). Categorical perception of lexical tones in Chinese revealed by mismatch negativity. *Neuroscience, 170*, 223–231. https://doi.org/10.1016/j.neuroscience.2010.06.077

Yarbay Duman, T. & Bastiaanse, R. (2009). Time reference through verb inflection in Turkish agrammatic aphasia. *Brain and Language, 108*, 30-39.

Yiu, E. M. L. & Fok, A. Y. Y., (1995). Lexical tone disruption in Cantonese aphasic speakers. *Clinical linguistics and Phonetics, 9*, 79-92.

Yu, K., Wang, R., Li, L., & Li, P. (2014). Processing of acoustic and phonological information of lexical tones in Mandarin Chinese revealed by mismatch negativity. *Frontiers in Human Neuroscience, 8*, 729. https://doi.org/10.3389/fnhum.2014.00729

Yu, K., Zhou, Y., Li, L., Su, J. A., Wang, R. & Li, P. (2017). The interaction between phonological information and pitch type at pre-attentive stage: An ERP study of lexical tones. *Language, Cognition and Neuroscience, 32*, 1164–1175. https://doi.org/10.1080/23273798.2017.1310909

Yue, J., Bastiaanse, R. & Alter, K. (2014). Cortical plasticity induced by rapid Hebbian learning of novel tonal word-forms: Evidence from mismatch negativity. *Brain and Language, 139*, 10– 22.

Zagona, K. (2003). Tense and anaphora: Is there a tense-specific theory of coreference? In Barss, A. (ed.) *Anaphora: A Reference Guide*. (pp. 140-171). Oxford: Blackwell.

Zagona, K. (2013). Tense, aspect and modality. In Dikken, M. den (ed.) *The Cambridge Handbook of Generative Syntax*. (pp. 746-792). Cambridge: Cambridge University Press.

Zatorre, R.J. & Belin, P. (2001). Spectral and temporal processing in human auditory cortex. *Cerebral Cortex, 11*, 946-953

Zatorre, R. J., Belin, P. & Penhune, V. B. (2002). Structure and function of auditory cortex: music and speech. *Trends in Cognitive Science 6*, 37–46. (doi:10.1016/S1364-6613(00)01816-7).

Zatorre, R.J. & Gandour, J.T. (2009). Neural specializations for speech and pitch: moving beyond the dichotomies. Philosophical transactions of the royal society. Series B: *Biological Sciences, 363*, 1087-1104.

Zheng, H. Y., Minett, J. W., Peng, G., Wang, W. S. Y. (2012). The impact of tone systems on the categorical perception of lexical tones: an event-related potentials study. *Language Cognition and Neuroscience, 27*, 184–209.

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PROPOSITIONS

1. There is a bi-hemispheric involvement in grammatical tone processing.

   - This dissertation (Chapter 2)

2. While grammatical tone perception is impaired in both individuals with left and right hemisphere damage, non-linguistic tone perception is more affected in individuals with right than left hemisphere damage.

   - This dissertation (Chapter 2)

3. Agrammatic aphasic speakers show more problems in processing verb forms referring to past than those referring to non-past, and thus, an impairment in grammatical tone perception is largely driven by an impairment in past time reference.

   - This dissertation (Chapter 3)

4. The past time reference deficit in agrammatism exists irrespective of the form in which it is expressed – whether through affixations, aspectual adverbs or grammatical tone.

   - This dissertation

5. Individuals without brain damage show different brain responses for violations for past and present time reference.

   - This dissertation (Chapter 4)

6. It is recommended that tonal processing abilities of agrammatic speakers of tonal languages are examined to ensure proper diagnosis and treatment.

   - This dissertation

7. Who controls the past controls the future. Who controls the present controls the past.

   - George Orwell, 1984

8. The human brain is a funny thing: it's very susceptible to tempo and melody. You put the right words to it, and it becomes very influential.

   - Ray Stevens

9. Not everyone who chased the zebra caught it, but he who caught it, chased it.

   - African proverb

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