EEG CEREBRAL LOCALIZATION OF TONE

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We know for certain that the Wernicke's and Broca's areas of the brain are primarily responsible for segmental speech initiation, processing and comprehension. Such accurate localization has yet to be established for supra-segmental speech operations like tone, stress and intonation. This study is a preliminary attempt to determine the parts of the brain responsible for tonal processing. The operative null hypothesis (H_o) is that there should be no significant difference in wave activity of any sector of the brain, whether a subject speaks a non-tonal language or a tonal language. An alternative experimental hypothesis (H_A) is that there should be significant difference in wave activity in a sector of the brain when a subject speaks a tonal language as opposed to a non-tonal language. There were four voluntary participants, all of whom were bare-scalped right handed normal adult male bilingual speakers of English and Yoruba. Cerebral activity of each participant was observed with an electroencephalograph (EEG), while listening to narratives first in English and then switching to Yoruba; and in reverse order. Another set of EEG were captured while each subject spoke English and then spoke Yoruba; and in reverse order. There was remarkable increase in amplitude and inharmonic trajectory of EEG alpha waves in the frontal lobes of left and right hemispheres of the brain upon transfer of perception or production from English to Yoruba. This pattern was reversed with a switch to English. Since it is already established that the left cerebral hemisphere is the seat of segmental speech for non-southpaw individuals; we are persuaded to adduce the extra wave activity in the right hemisphere during Yoruba activity to tonal processing. Hence the experimental hypothesis wins.

Les aires Wernicke et Broca du cerveau sont bien connues comme responsables de premier plan de l'initiation du langage articulé, de son traitement et de sa compréhension. L'on n'a pas encore réussi à établir une localisation aussi précise pour des opérations du langage articulé telles que le ton, l'accent et l'intonation. Dans cette étude préliminaire, nous tentons de déterminer les parties du cerveau responsables du traitement du ton. L'hypothèse opérationnelle nulle (H_0) serait qu'il ne devrait pas y avoir une différence significative dans l'activité des ondes à n'importe quel secteur du cerveau, selon que le sujet parle ou non une langue à ton. Une hypothèse alternative expérimentale (H_A) serait qu'on observerait une différence significative dans l'activité des ondes dans un secteur du cerveau lorsqu'un sujet parle une langue à ton et que, par contre, une telle activité serait absente lorsqu'on parle une langue sans ton. L'expérimentation a porté sur 4 participants volontaires qui étaient tous, droitiers, adultes mâles normaux, droitiers n'ayant pas de cuir chevelu et locuteurs bilingues de l'anglais et du yoruba. L'activité cérébrale de chaque participant a été observée à l'aide d'un électroencéphalographe (EEG), pendant qu'il écoutait les récits d'abord en anglais, ensuite en yoruba.; et dans l'ordre inverse. Une autre série de EEG a été enregistrée pendant que chacun des sujets parlait anglais et ensuite Yoruba, et dans l'ordre inverse. On a observé une augmentation remarquable dans l'amplitude et la trajectoire non harmonique des ondes alpha EEG dans les lobes frontales des hémisphères gauche et droite du cerveau lors du transfert de perception ou de production de l'anglais au yoruba. Ce modèle était inversé lorsqu'on changeait en anglais. Dès lors qu'il est établi que l'hémisphère cérébrale gauche est le siège du langage articulé pour les individus normaux, nous sommes persuadés de devoir imputer l'activité supplémentaire de l'onde à l'hémisphère droit dans le traitement du ton lors de son activité en yoruba. L'hypothèse expérimentale est donc concluante.

0. INTRODUCTION

Tone has not been isolated and localized in the brain. This is largely because the concentration of cognitive experiments has been on segmental articulation, perception and comprehension; and it has long been assumed that supra-segmental phenomena are intrinsically linked to the segment. Whereas this atomic model of speech has been substituted with the autosegmental tier model of Goldsmith (1976), little attention has been paid to its relevance in cognitive science. We therefore, hereby, join a handful of attempts to delineate the area of the brain responsible for tonal operation. The experiment involved electroencephalographic (EEG) observation of brain activity while subjects performed articulatory and perceptual tasks switching between English (an atonal language) and Yoruba (a tonal language). By so doing, we tested the null hypothesis (H_0)that there should be no significant wave activity in any sector of the brain whether a subject speaks or perceives a tonal or an atonal language. The competing alternative hypothesis (H_A) was that there should indeed be significant difference in wave activity in sector(s) of the brain when a subject speaks or perceives a tone language as against an atonal language.

The paper is laid out in eight sections; the first of which is a sketch of the human brain and the category of persons appropriate for experiments on language and the brain. Section two is a summary of Yoruba tonal typology, followed by a short review of cerebral localization efforts in Section 3. Levels of invasiveness of different types of instrumentation for cerebral investigation are discussed in the fourth section, which also explains why EEG was used. Section 5 points out the rationale behind isolating tonal from segmental localization. Methodology and experimental procedure are described in Section 6; followed by interpretations and corroborations in the seventh section, while tentative conclusions are made in Section eight.

1. ABOUT THE HUMAN BRAIN

The human brain has a billion neurons bundled into three parts – cerebrum, cerebellum and brain stem; each of which performs roles complementary to the others. There are two cerebral hemispheres linked together by a bundle of fibres called the corpus callosum. The corpus callosum extends sagitally across the base of both cerebral hemispheres. The left cerebrum is usually the seat of cranial intellection, with its frontal, temporal and parietal lobes accommodating the Wernicke’s and Broca’s areas which serve as epicentre for speech coordination (Angevine 2002:313 and Schmidt, 1999:25-34). The human brain has undergone rapid growth in recent evolution, during which it doubled in size in less than one million years. The areas of the brain that experienced greatest development are those which deal with language (Wills, 1993:46-50). A minority of individuals referred to as being of southpaw (i.e. left-handed) have their speech areas situated in the right cerebral hemisphere. For reasons of uniformity, and in tandem with standard practice, only non-southpaw (right-handed) persons are admitted for linguistic cerebral investigation.

2. BRIEFS ON THE YORUBA TONE SYSTEM

Yoruba has three discrete level tones, whose frequencies are set apart and may not overlap. Every speaker has absolute ranges of pitch for high, low and mid tone; meaning that the pitch of a high tone may never get as low as that of a mid tone, and that of mid may not go as low as a low tone. Each speaker's tone operates within a particular pitch range.

In Yoruba orthography, the high tone is marked with the acute sign (́), the low tone with the grave sign (̀), while the mid tone is unmarked. Thus, any vowel without a tone in orthography carries a mid tone. Fig. 1 is an acoustic illustration of lexical distinction occasioned by Yoruba tonemes.

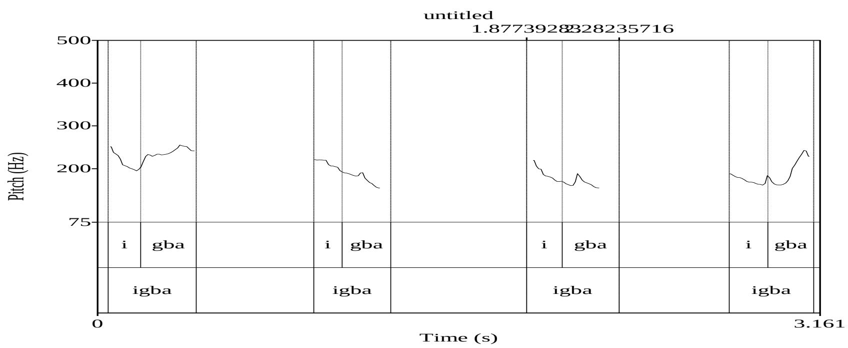

Fig. 1: Yoruba Tonal distinctions, **īgbá** 'calabash' **īgbà** 'climbing rope' **ìgbà** 'time' **ìgbá** 'garden egg'

3. CERERAL LOCALIZATION IN PERSPECTIVE

In 1796, Austrian physician Franz Joseph Gall (1758-1828) hypothesized that different mental functions reside in specific parts of the brain. That was the beginning of phrenology, the first complete theory of cerebral localization. Following from that, the French surgeon, Pierre Paul Broca (1824-1880), localized the speech production at left pars opercularis and triangularis areas adjacent to the motor cortex of the brain. Those areas hence became the Broca's area (Bulsara et al., 2005:1). Sequel to that discovery, Carl Wernicke a German surgeon localized language comprehension around the left temporal and parietal lobes, hence the name Wernicke's area (Geschwind, 1972:77-79).

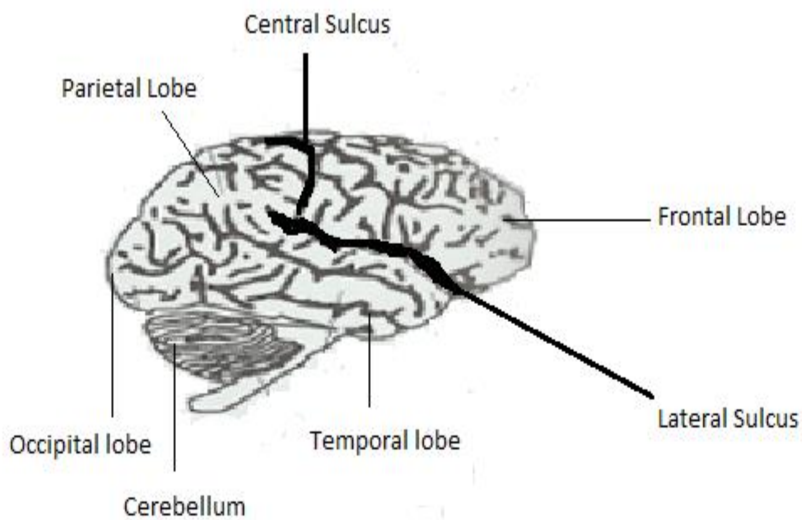

Fig. 2: Right hemisphere of the human brain showing sulci and lobes

Further still, Brodmann (1909) cited in Angevine (2002:313-371) did an elaborate Nissl stain aided cyto-architectural delineation of the cerebral cortex into 52 parts. He assigned Areas 44 and 45 to the Broca's Area (i.e. pars opercularis and pars triangularis respectively); and collectively mapped Areas 22 (superior temporal gyrus), 39 (angular gyrus), 40 (supramarginal gyrus), 41 and 42 (primary and auditory association cortex) as Wernicke's Area. Deriving from Brodmann's localization, it was taken that the speech centres of the brain had been fully identified until scholars like Gandour et al (2000:207-222) began to investigate the parts of the brain responsible for tone in Chinese and Thai (see section 7.2). The current experiment is a participation in the mission to precisely localize cerebral tonal processing (*vide* Brodmann K. and J. Garey 2006).

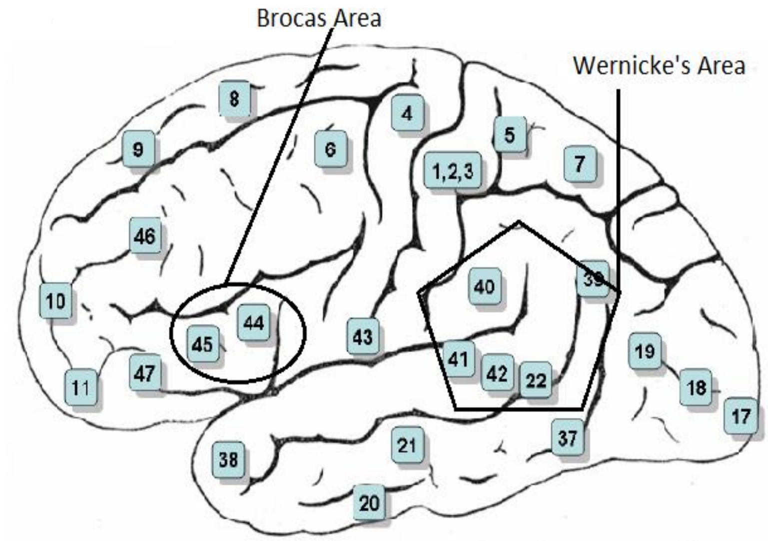

Figure 3: Left Hemisphere showing Bromann's numbering and speech areas

4. INSTRUMENTATION AND INVASIVENESS IN CEREBRAL INVESTIGATION

Every type of cerebral investigation involves digital data acquisition, albeit to varying levels of invasiveness. An experiment is invasive if it involves injecting a foreign substance into a subject or cutting the subject's body open to acquire data. Electroencephalography (EEG), the instrument used in this report, has the advantage of being the least invasive but the disadvantage of being most imprecise. An equally non-invasive yet more accurate method than EEG is functional Magnetic Resonance Imaging (fMRI), which scans the living brain and produces 3-dimensional images of brain activity in real-time. The fMRI was our preferred instrument, but we had to shelf the idea for later because the machine is currently not available in the collaborating laboratory. Positron Emission Tomography (PET) is an invasive method of cerebral observation, which involves the injection of glucose and a radioactivity tracer into participant's bloodstream; and,by far the most accurate means of cerebral investigation is Electrocorticography (EcoG). EcoGis however extremely invasive as it entails placing electrodes directly on the cerebral cortex to measure areas of increased electrical activity during speech production or perception.To achieve EcoG, the participant's skull must be broken open and the cerebral cortex left bare; a condition which may only be met if the participant has a precondition requiring cerebral surgical operation. Such patients however would scarcely have the presence of mind for meaningful linguistic investigation.

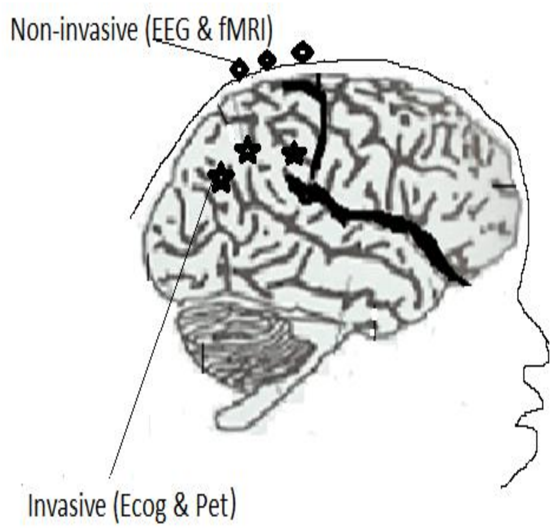

Fig. 4: Levels of invasiveness in cerebral investigation

Therefore, for reasons of financial ability and geographical proximity, we decided on the use of the EEG for this initial investigation. With the benefit of inferences from this preliminary work, we would then embark on a thorough fMRI project.

5. WHY SHOULD TONE DIFFER FROM SEGMENT IN CEREBRAL SPACE?

It is taken in neuroscience that every action of man is as a result of signals from specific neurons in the brain (Boeree, 2009:1-2). In like manner, tone, which is lexically significant pitch, should be processed and comprehended by specific neurons. The assumption that tone is intrinsic to sound segment has been poignantly discredited by Goldsmith (1976:36-37):

> If the "suprasegmental" of pitch, for example, does itself form a sequence of tonal segments, then, suprasegmental is a misleading label. A more accurate picture, we are suggesting, is parallel sequencing of segments, none of which "depend" or "ride on" the others. Each is independent in its own right, hence: the name, <u>auto</u>segmental level.

It follows therefore that the assumption should not be made that tone is processed in the brain just the same way segments are; especially because it has been proved that pitch related processes like music are coordinated in the right cerebral hemisphere of non-southpaw persons, whereas segments are coordinated in the left hemisphere. As Damasio and Damasio (1977:151) report:

> (1) musical faculty and cerebral dominance for verbal language are not intimately related; and (2) there is evidence for a sort of dynamic, developing cerebral dominance for certain features of musical faculty assuming the following aspects: (a) a right hemisphere dominance for

> musical execution, relativelyindependent of musical knowledge and training, and (b) a variable dominance for musical perception, to be ascribed to the right hemisphere…

Indeed, if the multi-tiered autosegmental approachhas gained wide currency, it should not be too difficult to imagine that each tier may be wired by different cerebral spaces along different pathways, which are ultimately linked.

6. METHODOLOGY

Using non-invasive EEG, we recorded cortical activities from the bare-scalp of non-southpaw individuals.There were fourmale volunteer participants, all of whom were undergraduate students of the University of Ibadan. The condition for selection was that participants were bare-scalped right handed normal adult male bilingual speakers of English and Yoruba, with no history of neurological, psychiatric, or auditory symptoms. EEG procedure was carefully explained to each would-be participant. Those who were willing to participate signed a consent form before research was conducted. The Linguisticaudio data that evoked perception was supplied by a female Yorùbánative speaker.

Perceptual activity involved listening to recorded narratives first in English (2 minute) and then switching to Yoruba (2 minutes), and in reverse order, while acquiring EEG images. Another set of EEG data were acquired while the subject spoke English (2 minutes) and then Yoruba (2 minutes), and in reverse order. The entire routine was carried out twice for each subject.

Cerebral activity of each participant was observed with an electroencephalograph (EEG), while listening to narratives first in English and then switching to Yoruba; and in reverse order. Another set of EEG were captured while each subject spoke English and then spoke Yoruba; and in reverse order. Labeled alpha wave trajectories were then observed for aberrant and peculiar patterns.

Conductive gel was first applied with a syringe to the scalp of participants, after which EEG electrode sensors were placedon the skull, spread out in such a way as to capture Brodmann's Areas on the cerebral cortex. Cerebral electrical activity was captured as waves on an EEG monitor. EEG measurement is not invasive; sinceit does not involve injecting or introducing any substance into a participant.There are four types of EEG waves, namely Alpha(α), Beta (β), Theta (θ) and Delta (δ) waves,with frequency ranges 8–12Hz, 12–30Hz, 4–7Hz and 0–3Hz, respectively. Healthy adults present with alpha waves, and only such persons may participate in linguistic experiments. One of theparticipants manifested Beta waves, another was of southpaw. Though, they manifested similar wave alterations to stimuli, we did not take their records into account during interpretations.

Fig. 5: EEG Procedure

Participants' alpha waves were first observed in three phases: silence, perception of English and perception of Yoruba via a headset. The same sequence was then followed for productionwhile they read prepared text in English and Yoruba. To reduce noise artefact (caused by non-linguistic observations) in waveforms,all EEG recording were acquired with participants' eyes closed.

7. INTERPRETATION OF EEG WAVES

The EEG records electrical activity of the brain as waveform printed on paper. Each EEG recording consists of parallel wave tracings of different aspects of the brain. At the extreme left of each sheet, there are labels indicating which part of the brain is represented by the corresponding waveform (Fig. 6). For instance, F means frontal lobe; P represents parietal lobe; T temporal lobe and O stands for occipital lobe. The combination Fp indicates the frontal pole, while z means that the electrode is at the centralfissure. In addition, there are numbers written after letters which indicate the position of electrode on the cerebral cortex. Odd numbers represent electrodes in the left hemisphere, while even numbers indicate those in the right hemisphere.There are two ways to tell increased activity: by the intensity of waveforms or by their irregular trajectories.

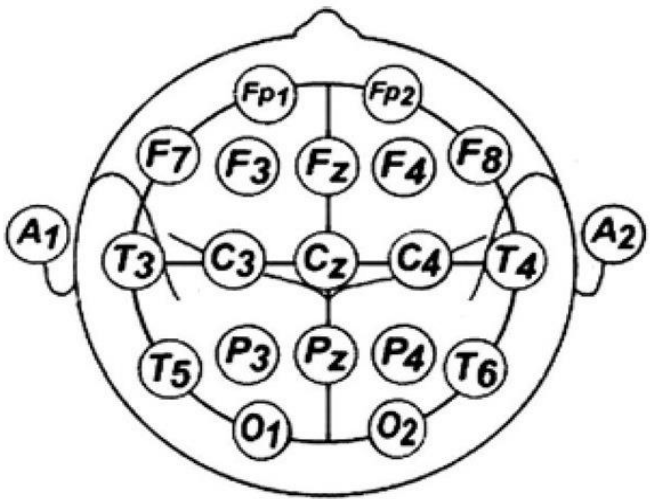

Fig. 6: EEG electrode Labels

Fig. 7: EEG Waves for Yoruba Perception

Figure 7 contains wave tracings during the perception of Yoruba. The areas of high intensity in Fig 7 are Fp1- F3(left); Fp1 – F7 (left); F7 – T3 (left); Fp2 – F8 (Right); F8 – T4 (Right). By implication, thereis increased activity in the frontal and temporal lobes of both left and right cerebral hemispheres. With respect to the relationship of tonal perception with Broca's area in the left hemisphere, this finding ties with that of Gandour et al (2000:208).

Regarding English perception, Fig. 8 reveals increased activity in Fp1 – Fp2 (left and right) and at P3 – Pz(left and mid right hemisphere). By implication the parietal region, which accommodates part of the Wernicke's area is involved in the perception of English. This is very different from the waves observed for Yoruba.There are baseline increments of wave activity in the right hemisphere, which remain marginal when compared with the robust effects seen in the right hemisphere during perception of Yoruba. It was also observed that the intensity of cerebral activity was higher during Yoruba perception.

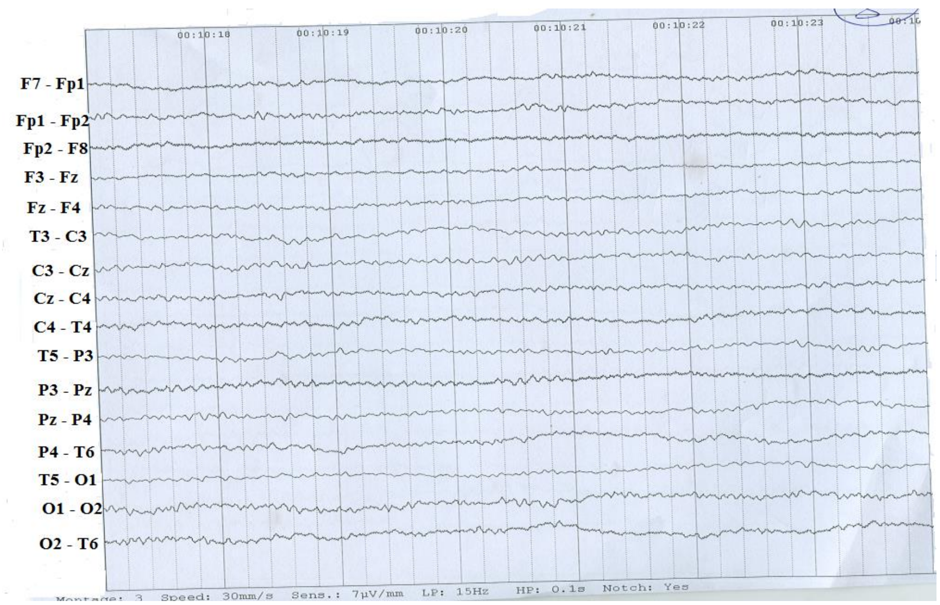

Fig. 8: EEG Waves for English Perception

Records of production (Fig. 9) show intense activity at electrodesF7 – Fp1, Fp1 – Fp2 and Fp2 – F8 for both English and Yoruba. These activities are however more intense with Yoruba. In addition there are alpha waves of higher amplitude at O2 – T6 (right hemisphere). Thus, regardless of common cerebral convolutions, Yoruba shows greater quantity and quality in the right hemisphere than English.

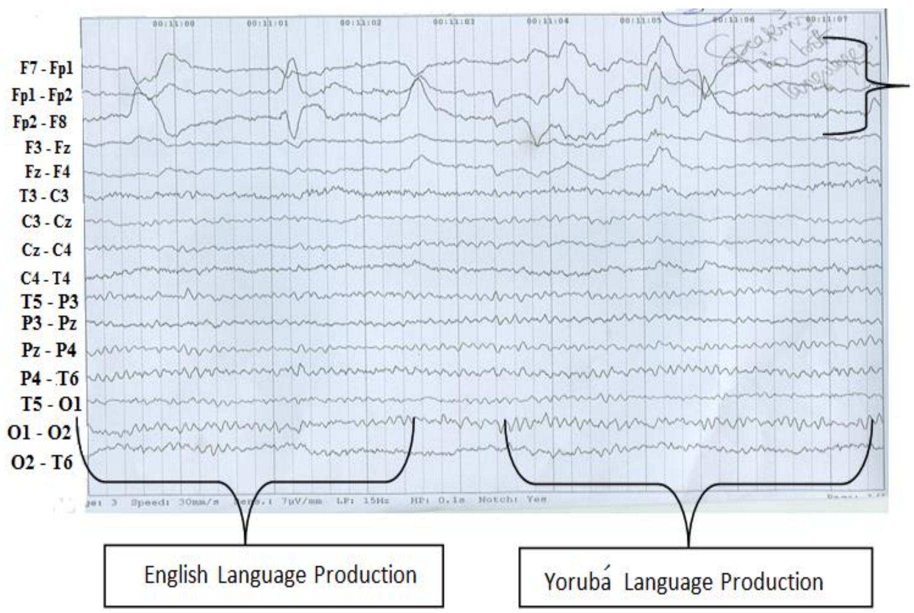

Fig. 9: EEG records for English followed by Yoruba production.

7.1 OUTCOME VARIABLES

In line with the H_A so proposed, it was observed that there was significant increase in wave amplitude of both hemispheres - p= 0.03 (left hemisphere) and p= 0.015 (right hemisphere) when subjects perceived tone. The figures for production of tone were p= 0.4 for left hemisphere and p= 0.3 for right hemisphere. These figures point albeit grossly to the involvement of the right hemisphere in the processing of tone. Precision pointing may only be achieved by fMRI.

7.2 CORROBORATION WITH COGNATE LOCALIZATION INVESTIGATIONS

Tone perception was the focus of Gandour et al (2000:207-222, 2012:1). They observed native-speaker perception of Chinese and Thai with PET, and reported an increase in cerebral blood flow in the left hemisphere, especially in the frontal lobe region, as well as marginal increase in the CBF around the brainstem. They also reported a semblance of tone baseline in the right cerebral hemisphere. Thus, they concluded that aside from Broca's activity, the brainstem may also be involved in tonal perception.

Taking a cue from the observations of Gandour et al (2000), and bearing in mind that they focused on perception alone, this experiment was designed to include tonal production. We therefore acquired EEG data on variance in electroencephalographic (EEG) activity during the production and perception of English and Yorùbá languages. Our results tie with those of Gandour et al (2000) regarding enhanced activity in the traditional speech centres. However, regarding the role of the right cerebral hemisphere, unlike Gandour et al., we recorded significant wave activity, which suggest that aspects of the right hemisphere are pivotal to tonal processing.

Wang et al. (2003:1025) used functional magnetic resonance imaging (fMRI) to monitor tone enhanced cortical modifications of the brain while participants learnt the lexical tones of Mandarin. They reported that there was enhanced sensation in the auditory cortex and the right inferior frontal gyrus. The Brodman's areas so affected are 22 (putative Wernicke's area), 42 and 44 (right inferior frontal gyrus). They inferred that sustained tonal activity resulted in the "expansion of preexisting language related areas and recruitment of additional cortical regions".

Whereas the Wang et al. (2003) experiment was of the chronic nature, focusing on modifications due to learning of Mandarin, our study was more acute as it observed real-time switch from a tonal to an atonal language. It may in fact be inferred that the cerebral modifications observed by Wang et al. resulted from tasking the brain in learning another language, and do not all necessarily derive from tonal acquisition. Our results are however in sync regarding the recruitment of additional cortical regions, which may just as well be in the right cerebral hemisphere. Our proposal for real-time fMRI during linguistic activity, rather than chronic observation after tonal acquisition should answer some questions.

8. CONCLUSIONS

Within the limits of EEG, it has been shown thatapart from the expected activity in the left hemisphere, there is considerable electrical commotion in the right hemisphere during tonal processing. It coincides with findings about musical dominance in the right hemisphere. This conclusion is however tentative for want of concrete experimental localization. Again, nothing can yet be said about the involvement of the brain stem in tonal activity since EEG electrodes do not probe the brain stem. However, sequel to the fact the left and right cerebral hemispheres are more prominent in production and perception of Yorùbáthan was recorded for English, we may hypothesize that aside from being processed in the right hemisphere; tone processing may also be localized in the brain stem. This last hypothesis may only be confirmed with more sophisticated equipment such as fMRI.

Further still, it may be discovered that several cerebral locations are excited during tonal operation. Should that be the case, the region with the highest proportion of excitement will be localized as the dominant area for tonal processing. However, pending the findings from more fMRI studies, the present submissionis that right hemisphere is the epicentre of tonal activity, with the added suspicion that there are distinct areas for tonal perception and production.

ABBREVIATIONS

EcoG	:Electrocorticography	Hz	Hertz (Unit of frequency)
EEG	Electroencephalogram	O	Occipital lobe of the brain
F	Frontal Lobe of the brain	P	Parietal lobe of the brain
fMRI	Functional Magnetic Resonance Imaging	PET	Positron Emission Tomography
Fp	Frontal Pole of the brain	T	Temporal lobe of the brain
H_0	Null Hypothesis	Z	Central fissure of the brain
H_A	Alternative Hypothesis		

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