Encoding *Frequency* in OT:
Frequency effect on stress preservation

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1. Introduction

Since English stress is involved with various idiosyncratic patterns, it is very difficult to give a complete account despite the volume of studies that have been done so far. The first pioneering work by Chomsky and Halle (1968) explains English stress as a product of interaction between cyclic and non-cyclic rules. This account, however, cannot be applied to all English words; it is not difficult to find apparent exceptions. The rule-based theory like this is destined to fail especially in case of English stress since it has abundant exceptions that cannot be measured by only a set of rules. In this sense, it is not exaggeration that Optimality Theory is more suitable than rule-based approach in explaining English stress pattern. Optimality Theory has succeeded in giving more improved account for, for example, metrical stress by Generalized Alignment (McCarthy and Prince 1993). Nevertheless, English stress is yet far from being fully explained. Since English stress is basically involved with lots of lexical idiosyncrasies, we need a tool to handle these lexical differences.

Against this backdrop, Pater (2000) proposes a lexically-specific constraint, which is applied to a set (S_1 or S_2) of words to explain lexically-specific English secondary stress. This is one-step advanced approach in that we can apply different constraints and rankings to different lexical items. However, how do we know whether a word belongs to S_1 or S_2? If the answer is that S_1 tolerates violation of *Clash-Head while S_2 does not, it can be circular reasoning.

To avoid hasty generalization that lexically-specific constraints exist, we should consider factors behind the seemingly lexically divided sets. One of them is *frequency*, as pointed out by Hammond (2003), which demonstrates that the more frequent the form is, the more likely it is to undergo vowel reduction. This paper further investigates frequency effects on English stress by corpus-based study and proposes how to incorporate frequency into grammar.

2. Previous studies

2.1. Chomsky and Halle (1968)

Chomsky and Halle (1968) shows the effect of stressed vowel in the first cycle on the stresses in the second cycle. They illustrate phonetic effects of the rules of the transformational cycle. The vowel in the second syllable of *condense* is stressed, and this is reflected in the nominalized word *condensation* in the next cycle. Another effect of cyclicity is vowel reduction. Consider the examples below.

(1) (a) $[_N[_V\text{condens}]_V\text{At+ion}]_N$ (b) $[_N[_V\text{devastAt}]_v\text{tion}]_N$

(a)			(b)	
	1		1	2
	2	1	2	1
2	3	1	3	1
3	1	1		

The second vowel in (1a) *condensation* is unstressed but remains unreduced because it is the primary stress in the first cycle. The corresponding vowel of (1b) *devastation*, in contrast, is reduced, as it bears no stress in the first cycle. Thus, it seems that the primary stress in the first cycle is preserved in the second cycle. However, the cyclic stress preservation approach has been criticized by Halle and Vergnaud (1987) and Halle and Kenstowicz (1991) since it should assume considerable exceptions.

2.2. Halle and Kenstowicz (1991)

Contrary to Chomsky and Halle (1968), Halle and Kenstowicz (1991) indicates that the cyclic stress preservation occurs only in a limited set of words such as *condénse -còndénsátion*. It also applies to the words like *còn<u>tem</u>plátion* which does not bear any stress in the first cycle *còn<u>tem</u>pláte*. However, this is not true for the cases like the following (Halle & Vergnau 1987).

(2)(a)	(b)
affírm	áffirmátion
confírm	cònfirmátion
consérve	cònservátion
consúlt	cónsultátion
convérse	cònversàtion
infórm	ínformátion
lamént	lámentátion
presérve	prèservátion
transpórt	trànsportátion
usúrp	ùsurpátion

The second syllables of (2a) have no stress though they are the primary stresses in the previous cycle as in (2b). Cyclic stress preservation of Chomsky and Halle (1968) is awkward for these cases.

Halle and Kenstowicz (1991) propose that the subsidiary stresses are assigned by a noncyclic rule that metrifies the string of unstressed syllables preceding the cyclically assigned stress. Therefore, they view the stress rules of English as (3). English primary and secondary stresses are assigned in the different levels of cycle: cyclic and noncyclic respectively. The metrification direction for the primary stress is from right to left, and vice versa for the secondary stress.

(3)	
Cyclic	Stress Erasure Convention
	Stress heavy syllables
	Metrification (right to left)
	Conflation
Noncyclic	Stress heavy syllables (lexically restricted)
	Metrification (left to right)

The rule assigning stress to heavy syllables operates in both the cyclic and the noncyclic blocks but its operation in the latter stratum is *lexically* restricted, applying in *condensation*, *deportation*, *incantation*, *Halicarnassus*, but not in *compensation*, *transportations*, *information*, *serendipity*. In sum, cyclic and noncyclic rules are applied partially on the lexical basis.

2.3. Pater (2000)

Let us now turn to an Optimality-theoretic account for English secondary stress. Since Optimality Theory does not admit the concept of derivation, cyclic and noncyclic rules cannot mean a lot any more. Only surface form is important to decide whether a syllable is stressed or not. Whether the syllable of the base form has stress or not is far from the focus. Yet still, the stress of the base form can be considered even though not always respected in the form of OO constraints (Benua 1997).[1] English has a tendency to avoid clash between adjacent syllables, which is translated into the constraint like *Clash-Head. The interaction of these two constraints is the main force that decides whether a syllable bears subsidiary stress or not.

The examples in Pater (2000) can be classified as follows. The words in (4) never preserve the base stress, (5) preserve the stress of the base, and cyclic stress is variably preserved in (6).

(4) Cyclic stress NOT preserved

infòrm - ínformátion	convérse - cònversátion
trànspórt - trànsportátion	confírm - cònfirmátion
trànsfórm - trànsformátion	lamént - làmentátion
consúlt - cònsultátion	phonétic - phònetcian
consérve - cònservátion	cosmétic - còsmetcian

(5) Cyclic stress preserved

commúnal - còmùmnálity	condénse - còndènsátion
cònglòbáte - cònglòbátion	contsét - còntèstátion
crèáte - crèàtívity	detést - dètàstátion
denóte - dènòtátion	doméstic - dòmèstícity
èxclúsive - èxclùsívity	elástic - èlàstícity
exhúme - èxhùámtion	incrúst - ìncrùstátion
immóbile - ìmmòbílity	infést - ìnfèstátion

(6) Variably preserved

advántage - àdvànátgeous (K-, W-)
àugment - àugmèntátion (K+, W-)
áuthéntic - àuthèntícity (K-, W+)

In (5), cyclic stress is preserved even though first and second syllables induce stress clash. In terms of constraint, ID-Stress is ranked higher than *Clash-

1) Clearly, this must be an improvement from rule-based theory. In rule-based point of view, stress preservation should take place in all words. If some do not observe the rule, they must be regarded as exceptions.

Head.

(7) ID-Stress
If α is stressed, then $f(\alpha)$ must be stressed.

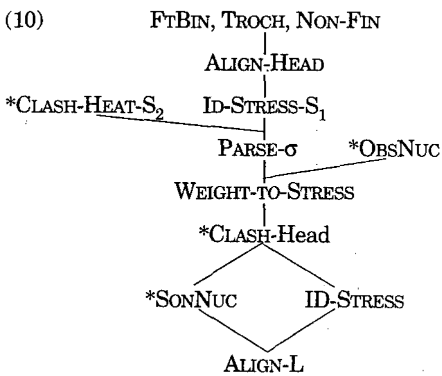
(8) *Clash-Head
No stressed syllable may be adjacent to the head syllable of the Prosodic Word.

The higher-ranked ID-Stress in this case is applied only to the words like (5). Pater (2000) proposes a lexically-specified constraint ID-Stress-S_1 and lists the words like (5) in the set S_1, and S_1 = {*condensation*, *apartmental*, *chimpanzee*}. The ranking is as follows:

(9) ID-Stress-S_1 Parse- σ ≫*Clash-Head ≫ ID-Stress

Conversely, base stress is never preserved in the examples (4), nor the stresses clash each other. It means that to avoid stress clash is more important than to preserve stem-stress. For the lexical items like this example, Pater (2000) proposes another lexically-specific constraint, *Clash-Head-S_2. S_2 contains lexical words such as (4). What follows is the overall grammar proposed by Pater (2000).

(10)



Where
S_1 = {*condensation*, *apartmental*, *chinpanzee* ...}

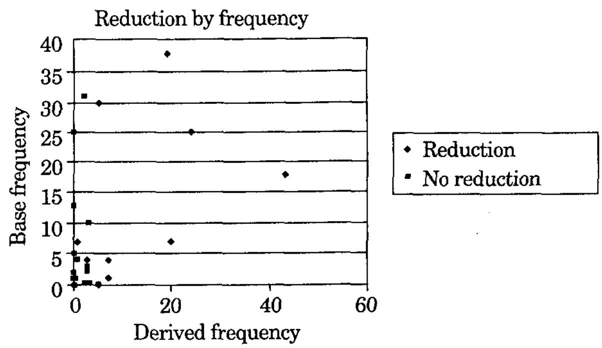
S_2={admire, companion, *Altanta*, *Kilimanjaro*, *representation* ...]

2.4. Hammond (2003)

The main idea of Hammond (2003) is that lexical frequency of the stem can affect the pronunciation of a derived word. He cites Fidelholtz (1975): frequency affects reduction of initial heavy syllables. Compare the high-frequency word *astrónomy* with the lower-frequency word *gàstronómy*. The initial vowel of the former high-frequency word is reduced while the latter is not. Besides that, he argues rhythm is more likely in higher-frequency phrases than in lower-frequency phrases, as in *bámbòo cúrtain* (high frequency) and *bàmbóo fénce* (lower frequency).

To test frequency effect on vowel reduction, he collected English nouns ending in *-ation*, along with their putative bases, e.g. *trànsfórm* - *trànsformation* from the Brown Corpus.[2] The result is that the more frequent the base form is, the more likely the derived form is to undergo reduction. As the following graph demonstrates.

(11)



Note that Hammond (2003) argues this kind of frequency effect is not what we would expect. Rather, a naive relation of frequency and reduction should be deemed such that the more frequent the base form is, the less likely the corresponding vowel of the derived word undergoes reduction, for we hear the full vowel of the base form more often. This is exactly the inverse of what really happens. He states it as an *inverse function of lexical frequency*.

The next task is to encode frequency in the grammar. He did not directly incorporate frequency into the grammar, but merely make it *heeded* by the grammar. Citing Pater (2000), the effect of cyclicity is obtained through the

2) Brown Corpus has approximately 1 million American English words, developed in 1960's

correspondence constraint Ident-Stress-S_1, where specific lexical items are specified in the constraint. The words listed in S_1 are those that preserve stem-stress, following the inverse function of lexical frequency.

For example, the word *rèpresentátion* has sufficiently high frequency enough to undergo vowel reduction, and thus it is not included in S_1. On the other hand, the word *èxáltátion* is sufficiently infrequent to block vowel reduction. Hence it is included in S_1. In this way, frequency has become incorporated or at least heeded in the grammar.

Hammond indicates some problems involving Pater (2000). First, it does not generalize to new words. For maximally infrequent forms (i.e. a new word that has not yet been heard), how can they be listed among the forms referred to by ID-Stress-S_1 when the form has not been even heard yet? The second problem is that it cannot be applied to phrasal rhythm.

The solution proposed by Hammond (2003) is as follows: Instead of listing lower-frequency words in the faithfulness constraint ID-Stress (...), list high-frequency words in the markedness constraint Clash-Head (...). The difference is that now the *most* frequent items are indicated by the constraint, which is a finite set. This solution can treat the new-word problem mentioned above, for we do not need to consider a new word at all. Look at the tableau (12).

(12)

/transformation/	CLASH-HEAD(...)	IDENT-STR
☞ [trànsfor] [má] tion		*
[taáns] [má] tion	*!	
/exaltation/	CLASH-HEAD(...)	IDENT-STR
[èxal] [tá] tion		*
☞ [èx] [àl] [tà]tion		

Since *transformation* is more frequent than *exaltation*, *transformation* is listed in the constraint Clash-Head (...), but *exaltation* is not. Therefore, *exaltation* vacuously satisfies Clash-Head(...).

Two problems arise from this analysis. First, admitting the motivation for lexically-specific markedness constraint rather than faithfulness constraint, it seems unnatural to list less marked items. Clearly, the (ˋ___ ___ ˊ___) pattern is less marked than (ˋ___ ˋ___ ˊ___) since rhythm rule to avoid stress clash is predominant in English. It is more natural to list or mark the marked items and do nothing with unmarked items. Second, the way he encoded frequency is not direct though his objective is modeling frequency effects with OT. Problem is that there is no clear standard for how frequent a word must be to be included a given constraint. Rather, his solution can be viewed as mere description of S_1 and S_2 of Pater (2000) in terms of frequency.

In this respect, I will answer to these problems: i) in my solution, more marked items (i.e. less frequent items) will be affected by the specific constraint, ii) frequency will be *directly* encoded in the grammar. Let us turn to the next section for my proposal.

3. Research

This section pursues answering two questions: "Is *frequency* an effective factor in English secondary stress?" and "If so, how can the frequency factor be encoded in the grammar?" Each subject is discussed in the following subsections 3.1 and 3.2 respectively. The tool and corpora used are as follows:

- **Tool:** WordSmith 4.0.0.93(2003-11-24) for Windows 95/98/NT/2000/XP
- **Corpora:**

BROWN	Brown Corpus of American English	1 million words	1960's
FROWN	Freiburg-Brown Corpus of American English	1 million words	1990's

To use larger data size, I use two corpora, BROWN and FROWN together (total 2 million words). They are American English words from 1960's and 1990's.

3.1. Frequency effect

The fact that frequency is influential in stress assignment is apparent on the basis of the previous studies such as Fidelholtz (1975) and Hammond (2003). To verify that frequency is influential, I perform a corpus-based research with the data from Pater (2000: 264). The original data is slightly modified: I reclassified the words that show variations in both (13a) and (c) into (b). Three groups are classified according to stress of initial vowel: (a) stressless (b) stressless or stressed (variable) and (c) stressed. The number on the right of each word is raw counts searched in BROWN and FROWN Corpus. The assumption is that less frequent words have initial stress in order to make the word distinctive and sound clear.

(13) (a) **Stressless:**

example	639	exact	61	enlarge	12	endeavour	1
except	319	extend	60	compose	9	enjoin	1
entire	275	congressional	57	compulsion	9	extinguish	1
concern	208	excuse	57	condemn	9	extravagance	1
advantage	146	companion	45	conceur	7	admonitory	0
executive	140	observe	45	confer	5	combust	0
advance	109	embrace	41	convention	5	confection	0
exetreme	106	exceed	35	endow	5	conflate	0
protect	106	convenient	34	propel	5	excrete	0
convention	99	engage	34	embody	4	exhume	0
conduct	97	propose	28	compress	3	obtrude	0
express	84	expose	21	enlighten	2	obtuse	0
enjoy	77	advise	19	entice	2	obvert	0
promote	71	compassion	15	excursion	2		
obtain	65	admire	14	prolong	2		

(b) **Stressless/stressed (variable):**

project	269	eccentric	19	accentuate	2	exhale	0
produce	186	accessible	18	admonish	2	pronominal	0
conflict	172	accelerate	9	adverbial	2	obsess	0
accept	153	administer	8	proloferate	2	obstetric	0
object	146	adversity	8	absolve	1	concretion	0
concrete	81	abnormal	7	abstruse	1	conglobate	0
admit	68	profess	7	concoct	1	empire	0
abstract	62	adhere	6	concordance	1	emporium	0
profound	49	abdoninal	5	obverse	1	enteric	0
acknowledge	38	obscene	5	progenitor	1	protract	0
obscure	37	emphatic	4	abduct	0		
proceed	35	extraneous	4	abhor	0		

absurd	31	obstruct	4	abstemious	0
adverse	28	accessory	3	admixture	0
absorb	25	obsequious	3	concelebrate	0

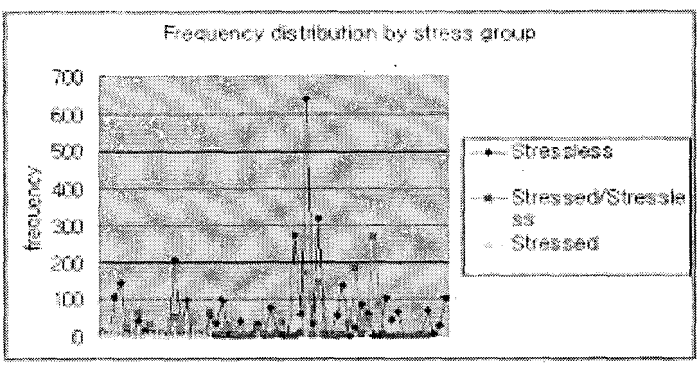
(c) **Stressed**

exogamy	2	advection	0
abscissa	1	excreta	0
agnomen	1	expropriate	0
excursus	1	exsect	0
extrinsic	1	extorse	0
protrude	1	obtest	0
abscond	0	obtund	0
admeasure	0	proscenium	0
adsorb	0	prosector	0

What we expect is the frequency average to be (a) > (b) > (c). The result average is (a) = 55.03, (b)=25.53, (c) = 0.39. This is exactly as we expected. The more frequent a word is, the more likely the initial vowel is reduced.

We can also see that the distribution of frequency is different from each group as shown in the following graph (14). Each dot represents each word in (13). The words with no stress in the initial position (13a) show higher distribution and the highest frequency. The words in (13b) appear in between two groups. The words of (13c) have strikingly low frequency, emerging at the bottom line.

(14)



The graph (14) apparently shows the tendency that stress-initial words are infrequent. Now let us turn to English secondary stress, which is the main concern of this paper.

3.2. English Secondary Stress

To prove the relation of frequency and English secondary stress, I counted each word in the examples above (4) and (5) in 2.3. (4) is the examples of stress non-preservation, and (5) is those of stress preservation. Therefore, we expect (4) to be frequent and (5) to be infrequent. Look at the count result below (15) and (16). The number on the right to the word means its count in corpora.

(15) Examples of cyclic stress non-preservation (\`__ __ _´ type)

infórm	21	ìnformátion	542	consúlt	28	cònsultátion	20
convérse	5	cònversátion	109	confírm	37	cònfirmátion	14
trànspórt	38	trànsportátion	97	lamént	5	làmentátion	1
consérve	10	cònservátion	60	phonétic	2	phònetícian	0
trànsfórm	23	trànsformátion	56	cosmétic	9	còsmetícian	0

Frequency Average (for derived words only) = 81.82

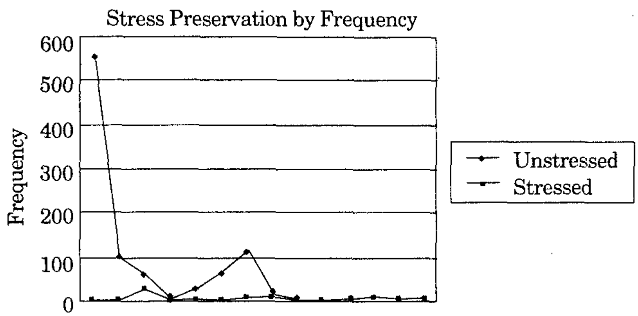
(16) Examples of stem-stress preservation (\`\_ \`_ _´ type)

crèáte	166	crèàtívity	24	commúnal	16	còmmùnálity	0
condénse	2	còndènsátion	8	cònglòbáte	0	cònglòbátion	0
elástic	8	èlstícity	5	denóte	19	dènòtátion	0
doméstic	159	dòmèstícity	4	èxhúme	0	èxhùmátion	0
immóbile	2	ìmmòbílity	4	contést	49	còntèstátion	0
infést	1	ìnfèstátion 2	2	detést	1	dètèstátion	0
èxclúsive	50	èxclùsívity 1	1	incrést	0	ìncrèstátion	0

Frequency Average (for derived words only) = 3.43

Following is the graph showing the frequency distribution by secondary-unstressed group (15) and stressed group (16). Each dot represents each word in (15) and (16). Similarly to the graph (14) in 3.1, the frequency of the stressed group of words is very low. The words in (15) that do not preserve the stem-stress are distributed with high frequency.

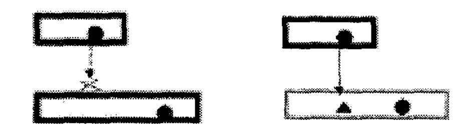
(17)



What differs from Hammond (2003) is that only the frequency of *derived word* is counted. I assume that base and derived word exist independently. In other words, perception of less familiar words depends on more familiar words. The frequencies of the bases in (15) tend to be lower than those of the derived words, while the frequencies of the bases in (16) tend to be higher than those of the derived words. Look at (15). Excluding two pairs *phonétic-phòntícian* and *cosmétic-còsmetícian*, of which the second syllables are light therefore unstressed, 5 out of 8 pairs (62.5%) are those in which the derived words are more frequent than their bases. In (16), however, 11 out of 14 pairs (78.6%) are those in which the base is more frequent than its derived counterpart. Since the derived words in (16) have lower frequency than their bases, the stress of the base is preserved in the derived words. The pronunciation of less frequent words are influenced by more frequent words.

The diagram (18) below will make clear what I argue. Frequency means familiarity. If we are familiar to a word, we do not need to refer to its stem any more. Conversely, if we are not familiar to a word, which means that the word has lower-frequency, we should depend on any related word such as base.

(18)



NOTE:
●: primary stress ▲: secondary stress
Each rectangle is a word. Rectangles with bold lines are frequent, familiar words. The rectangle with thin lines is infrequent, unfamiliar word.

The stress of the base does not need to be preserved when we are familiar with the derived words. For infrequent words, however, the base stress should be preserved in order to make the derived word easier to recognize.

3.3. Encoding frequency in the grammar

As we have seen, frequency is an influential factor for stress assignment. Now the final task is to incorporate frequency into the grammar. To do this, I propose the following constraint and ranking.

(19) ID-Stress($f \leq t$)
Preserve the base stress if the frequency *f* of the input is smaller than *t* (threshold).

Threshold is the minimum frequency that base stress may not be preserved.

(20) ID-Stress ($f \leq t$) ≫ *Clash-Head ≫ ID-Stress

Instead of lexically-specifying a constraint, frequency determines whether the ID- Stress ($f \leq t$) constraint is applied or not. The value t is the threshold, and it should be determined before EVAL process. If the frequency of the input is lower than the threshold, it should obey ID-Stress ($f \leq t$). In this way, if the frequency is not as high as the threshold, base stress will be preserved at the cost of stress clash.

It is most reasonable to use the highest frequency value in the stress-preservation group as threshold, for if the frequency is higher than that, stress will not be preserved. The highest count of the stem-stress preservation group (16) is 24 for *creativity*. To normalize, this raw count is divided by total number of words, 2000000. Therefore, the normalized frequency is 24/2000000 = 0.000012 . I will multiply this number with 10000 and use it to mean frequency (f), for example, f = 0.12 for *creativity*. Since this is the highest frequency in the stress preservation group, this f is the threshold frequency (t = 0.12). Now we have the constraint ID-Stress (f ≤ 0.12) in CON.

Look at the following tableau. Since *f* value (0.28) of *transformation* is bigger than *t* (0.12), the ID-Stress (f ≤ 0.12) is non-applicable. Therefore, the candidate that violates *Clash-Head cannot be selected as optimal, so the (21a) is selected. On the other hand, the *f* value (0.01) of *exaltation* is smaller than *t* (0.12). Thus ID-Stress (f ≤ 0.12) is activated in evaluation, and candidate (d) is selected as optimal output.

(21)

/transformation/f = 0.28	ID-Stress(f ≤ 0.12)	CLASH-HEAD	ID-STRESS
a. ☞ [trànsfor] [má] tion	N/A		*
[taáns] [fòr] [má] tion	N/A	*!	
/exaltation/f = 0.01	ID-Stress(f ≤ 0.12)	*CLASH-HEAD	IDENT-STR
[èxal] [tá] tion	*!		*
☞ [èx] [àl] [tà]tion		*	

It may seem problematic if you notice the frequency of *cònfirmátion* and *trànsformátion* in (15). The frequency of both words is as follows.

(25)

	Rawdata	Frequency	
a. cónfirmátion	14	f = 0.07	f < t
b. tránsformátion	56	f = 0.28	f > t

The frequency of (25a) is smaller than t and (25b) is bigger than *t*. However, they belong to the same group of words, that is, stress non-preservation examples. Both of them have the same ending *-ation*, which means that morphology cannot explain them.

In our theory, *f* should be bigger than *t*, for both (25a) and (25b) belong to the same stress non-preservation group. Therefore, we can assume that the frequency of (25a) *confirmation* is counted wrong in the first place. To prove this, I extended corpora with LOB and FLOB in addition to BROWN and FROWN.[3)]

The total number of words is now 4000000, doubled from 2000000. I searched for *confirmation* again and got the raw count of 44. The *f* value is then 44/4000000 = 0.000011 (f = 0.11).

Since the corpora are extended double, the threshold must also be recalculated on the basis of 4000000 words. The threshold word *creativity* is researched in the extended corpora, and the raw count is 33. The *f* value is then 33/4000000 = 0.000008 = 0.08% (f = 0.08 = t). Now that t = 0.08, ID-Stress(f ≤ 0.08) is not applicable to *confirmation since* f = 0.11 (f > t).

What we know from the above is that the larger and more precise the corpus is, the more correct result we get. We have seen that the frequency of *confirmation* is different when researched with 2000000 words and with 4000000 words. Thus the problem is with the size and preciseness of the corpora, not with the frequency theory in this paper.

4. Conclusion

Chomsky and Halle (1968) and Halle and Kenstowicz (1991) provide cyclicity account for English primary and secondary stress. To account for English secondary stress, Pater (2000) proposes the lexically-specific constraint. Recently, Hammond (2003) argues that frequency is crucial in determining stress placement. English secondary stress is a result of interaction of two forces: one for base stress preservation, the other for avoidance of stress clash. To avoid stress clash is more natural. However, infrequent words keep stem-stress to

3) LOB and FLOB are British English corpora, which contains 1 million words each.

LOB	London-Oslo-Bergen Corpus	1 million words	1960's
FLOB	Freiburg-LOB	1 million words	1990's

make them distinctive, tolerating stress clash.

This paper tried to show frequency effect on English word stress with corpus-based study, and to incorporate frequency into Optimality Theoretic grammar, proposing the constraint ID-Stress ($f \leq t$) and the hierarchy ID-Stress ($f \leq t$) ≫ *Clash-Head ≫ ID-Stress. Though frequency alone is the absolute element in stress assignment, it is clearly an interesting aspect in English stress phenomena.

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