ACOUSTIC CORRELATES OF METRICAL FEET IN TWO YUPIK LANGUAGES

McKinley Alden, Anja Arnhold

University of Alberta
malden@ualberta.ca, arnhold@ualberta.ca

ABSTRACT

Yupik languages are known for their complex iambic stress systems. Yup'ik (Central Alaskan dialect) and Alutiiq (Chugach dialect) both generate feet iteratively from left to right and distinguish stressed long, stressed short, and unstressed short vowels. Yup'ik only expresses metrical structure via stress. Alutiiq, however, has several systems that complicate metrical expression, often associated with its ability to form ternary feet amid binary sequences. These include stress, tone, and two types of lengthening (affecting binary or ternary foot heads), which are complicated by length neutralization.

Measurements of 2,238 and 2,235 vowels, respectively, from narrative recordings showed that both languages use duration, intensity, and maximum f0 to differentiate stressed and unstressed syllables while preserving phonemic length contrasts. Alutiiq prioritizes these contrasts even when the syllable is obscured by overlapping metrical processes. The results confirm descriptions of these languages' complex metrical systems.

Keywords: Prosodic typology, stress, acoustics, North American languages, speech rhythm

1. INTRODUCTION

In this paper, we contrast the acoustics of metrical expression in the Central Alaskan dialect of Yup'ik (henceforth *Yup'ik*) and the Chugach dialect of Alutiiq (henceforth *Alutiiq*), focusing on the acoustic correlates of stress. Yup'ik and Alutiiq are spoken in southwestern Alaska. They are sisters in the Yupik branch of the Inuit-Yupik-Unangan family, and are highly lexically and grammatically similar with a high degree of mutual intelligibility.

Closely related as they are, Yup'ik and Alutiiq share similar metrical systems, though with some crucial differences (see [1]–[4] and [5]–[10] on Yup'ik and Alutiiq prosody, respectively, as well as [11], [12] for a comparison). Both build iambic feet iteratively from left to right, e.g. Yup'ik *nalluyagucaqunaku* 'don't forget it' is footed (na.ˈɬu).(ja.ˈgu).(ʧa.ˈqu).(na.ˈku). Both have been described as non-culminative, such that there are no primary-secondary distinctions among stresses within the same word. Both further feature phonemic vowel quantity and quantity-sensitive stress, though which syllables are considered heavy differs between the two languages. In Yup'ik, all syllables containing phonemically long vowels are heavy (and thereby stressed), and closed syllables are always heavy word-initially. Elsewhere, a (C)VC syllable may or may not behave as heavy, e.g. *ayagtuq* [a.ˈjax.tuq] 'he leaves' vs. *up'nerkaq* [ˈup.nəχ.ˈkaq] 'spring'. In Alutiiq, (C)VC syllables are only heavy word-initially.

The most notable prosodic difference, however, is that where Yup'ik builds only binary iambic feet, Alutiiq can form ternary feet amid sequences of binary feet. That is, in Alutiiq sequences of light syllables, some appear to be 'skipped' in the assignment of binary feet [5], [10], [13], [14]. Martinez-Paricio & Kager [9] model this with the construction of Internally Layered Ternary (ILT) feet, e.g. ((ma.ˈŋaʁ).*su*).(qu.ˈta).(qu.ˈni)) 'if he (refl) is going to hunt porpoise', where the third syllable is an adjunct to a nested minimal iambic foot, so that the first three syllables are all part of an ILT foot. ILT foot heads, like the second syllable in the preceding example, receive 'additional lengthening' [5], [9]. Furthermore, where Yup'ik only expresses its metrical structure via stress, Alutiiq additionally uses metrically conditioned tone and foot-initial onset consonant fortition to express metrical structure [5], [10], [15]. Alutiiq also has a compression rule that neutralizes length contrasts. In closed and word-final syllables, this compression neutralizes the difference between an underlyingly long or stress-lengthened vowel and an underlyingly short vowel according to Leer [5].

Despite these detailed descriptions of the two prosodic systems, to date there has been little acoustical evidence to support these detailed descriptions (the only published acoustical study being [16]). Here, we present first results of a study exploring and comparing the acoustics of metrical expression in Yup'ik and Alutiiq. For Yup'ik, this entailed a study on the acoustics of stress production. For Alutiiq, a series of analyses explored the effects of stress and compression.

2. MATERIALS AND METHODS

This project analyzed six recordings of Central Alaskan Yup'ik [17], [18] and seven recordings of

Chugach Alutiiq [19]. All the recordings are housed in the Alaskan Native Language Archive [20]. Each recording was transcribed in Praat [21] at the segment level, with tiers for the intonational phrase (IP), the word, the syllable, and the segment. A Praat script [22] took measurements of duration (in ms), maximum fundamental frequency (f0) (in semitones relative to a baseline of 100 Hz, henceforth ST), and intensity (in dB; all recordings were first scaled to 70 dB) for all vowels in the data corpus.

The Yup'ik recordings contained 2,282 vowels and the Alutiiq recordings 2,320 vowels in total. For statistical modelling, words ten syllables (in Yup'ik) and nine syllables (in Alutiiq) or longer, which were rare, were removed. As a result, there were 2,238 vowels in the final dataset for Yup'ik and 2,235 for Alutiiq. Among the Yup'ik vowels, 506 were long (and thereby obligatorily stressed), 785 were short and stressed, and 947 were short and unstressed. For Alutiiq, 286 vowels were long (and obligatorily stressed), 891 were short and stressed, and 1058 were short and unstressed. For f0, measurements were occasionally not possible due to excessive creak, noise, poor recording quality, et cetera, so that the datasets used for the f0 models contained 2,164 Yup'ik and 2,072 Alutiiq vowels.

Analysis was done separately for each acoustic measure via linear mixed-effect models using the package lme4 in R [23]–[25]. Model selection began with a model containing only the stress-length distinction (stressed long, stressed short, and unstressed short), as a fixed effect, with file, speaker, and phoneme as the random intercepts. Further fixed effects were added only if they significantly improved model fit [23]. While complex random effects were tested, they either did not improve the fit of any of the models or caused convergence issues. P-values for fixed effects were obtained with the package lmerTest [26]. For models containing significant interactions, pairwise comparisons were performed with the lsmeans function from the package emmeans [27], using the Tukey method for p-value adjustments and the (default) Kenward-Roger method for calculating degrees of freedom.

For the sake of brevity, below we list all fixed effects included in the best-fitting model of each dependent variable, but only describe the effects of the main factor of interest, the stress-length distinction (and, for Alutiiq, compression).

In addition to individual models for each language, we also computed a model of each measure in a combined dataset containing both Yup'ik and Alutiiq data. These models were constructed specifically for direct comparison of the effects of the stress-length distinction in the two languages and therefore only contained an interaction between the stress-length distinction and language as fixed effects, and file and phoneme as random effects.

3. RESULTS

3.1. Duration

For the Yup'ik data, the best statistical model contained the stress-length distinction, word length and distance from the left edge of the word (in number of syllables), whether the vowel was in an IP-final syllable, the presence of an onset, and the presence of a coda as fixed effects. The results showed that long (obligatorily stressed) vowels were significantly longer than stressed short vowels ($\beta = 86.6617$; $SE = 24.027$; $df = 3.0165$; $t = 3.607$; $p = 0.03626$) and that unstressed short vowels were significantly shorter than stressed short vowels ($\beta = -32.969$; $SE = 2.5207$; $df = 2147.1971$; $t = -1.079$; $p = <2.00e-16$).

The Alutiiq model contained distance from the left edge of the word, IP finality, the presence of an onset, and the presence of a coda as fixed effects in addition to the stress-length distinction. Stress and length were both distinguished by duration: stressed long vowels were significantly longer than stressed short vowels ($\beta = 32.7295$; $SE = 1.9358$; $df = 2172.705$; $t = 16.9077$; $p = <2e-16$), and unstressed short vowels were significantly shorter than stressed short vowels ($\beta = -12.7909$; $SE = 1.3765$; $df = 2172.1648$; $t = -9.292$; $p = <2.00e-16$).

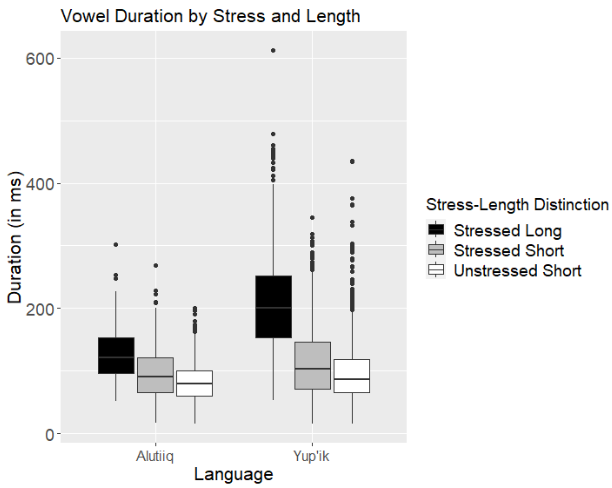

Figure 1: Boxplot of the duration of vowels by the stress-length distinction in Alutiiq and Yup'ik.

Thus, the duration linear mixed-effects models showed that, within each language, the stress-length categories were distinguished by their durations. However, the model directly comparing the two languages found the interaction between the stress-length distinction and the language to be significant. This means that the differences between the stress-length categories were not the same across the two languages, as illustrated in Figure 1. The difference between the mean duration of stressed long and stressed short vowels in Yup'ik was 96.91 ms, while the difference in Alutiiq was notably shorter at 32.64 ms, with Yup'ik having considerably longer long vowels than Alutiiq. The difference between mean duration in stressed and unstressed short vowels was more similar across the languages (15.87 ms in Yup'ik, 13.19 ms in Alutiiq).

Follow-up pairwise comparisons showed that stressed long vowels were significantly shorter in Alutiiq than in Yupik (β = -85.4; *SE* = 3.68; *df* = 4468; *t* = -23.204; *p* = <.0001). This pattern also held true for stressed short (β = -20.8; *SE* = 2.51; *df* = 4073; *t* = -8.296; *p* = <.0001) and unstressed short vowels (β = -21.5; *SE* = 2.34; *df* = 3893; *t* = -9.176; *p* = <.0001).

Finally, to test the effect of compression in Alutiiq, which is described as neutralizing length and stress distinctions by shortening vowels in stressed closed and word-final syllables, we fit a linear mixed-effects model containing only a five-level factor coding distinctions in stress, length, and compression as a fixed effect (stressed long compressed, stressed long uncompressed, stressed short compressed, stressed short uncompressed, unstressed short). It showed the durational differences between all these categories to be significant. Firstly, stressed long uncompressed vowels were longer than stressed long compressed vowels (β = 26.239; *SE* = 3.587; *df* = 2193.156; *t* = 7.315; *p* = 3.60e-13) and stressed short uncompressed vowels were longer than stressed short compressed vowels (β = 26.717; *SE* = 2.291; *df* = 2194.104; *t* = 11.664; *p* = <2e-16). This indicates that compression did work to shorten long and lengthened vowels. Secondly, compressed long vowels were significantly longer than compressed short vowels (β = 20.896; *SE* = 2.889; *df* = 2193.671; *t* = 7.233; *p* = 6.49e-13), indicating that length distinctions were still preserved even when the vowels were compressed. Lastly, unstressed short vowels were significantly shorter than both compressed long vowels (β = -25.722; *SE* = 2.788; *df* = 2193.424; *t* = -9.227; *p* = <2e-16) and compressed short vowels (β = -4.826; *SE* = 1.500; *df* = 2193.456; *t* = -3.218; *p* = 0.00131). This shows that the effect was not fully neutralizing—that is, that compression did not reduce a long or lengthened vowel to the duration of an unstressed short vowel, and furthermore, that length distinctions are preserved even in compression.

3.2. Intensity

For Yup'ik, the best model of intensity contained the stress-length distinction, distance from the left edge of the word, IP finality, the presence of an onset, and the presence of a coda as fixed effects. It showed that stressed long vowels were significantly louder than stressed short vowels (β = 1.2004; *SE* = 0.221; *df* = 2170.4585; *t* = 5.431; *p* = 6.21e-08), and unstressed short vowels were significantly quieter than stressed short vowels (β = -1.3019; *SE* = 0.1949; *df* = 2171.8781; *t* = -6.68; *p* = 3.03e-11). Relevelling also confirmed that unstressed short vowels had significantly lower intensities than stressed long vowels (β = -1.2004; *SE* = 0.2210; *df* = 2170.46; *t* = -5.431; *p* = 2.61e-08). Like duration, then, intensity was associated with the production of both long vowels and stressed vowels.

Regarding Alutiiq, the model also contained the stress-length distinction, distance from the left edge of the word, IP finality, the presence of an onset, and the presence of a coda as fixed effects. Stressed long vowels were significantly louder than stressed short vowels (β = 1.9127; *SE* = 0.2572; *df* = 2187.9845; *t* = 7.4373; *p* = 1.47e-13), and unstressed short vowels were significantly quieter than stressed short vowels (β = -1.3545; *SE* = 0.1863; *df* = 2184.5074; *t* = -7.2519; *p* = 5.68e-13).

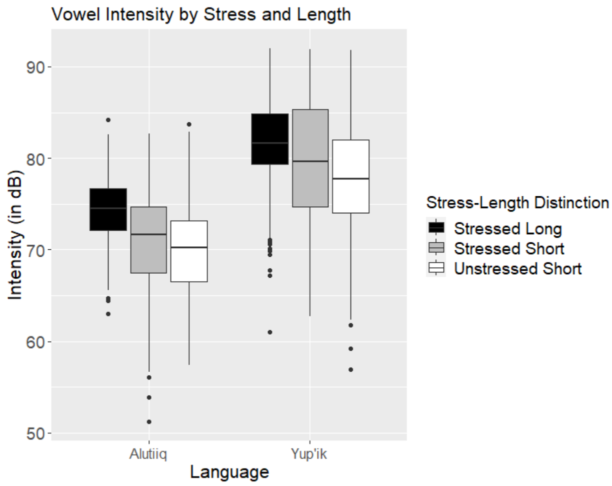

Figure 2: Boxplot of the intensity of vowels by the stress-length distinction in Alutiiq and Yup'ik.

In the model of data from both languages, the interaction between the stress-length distinction and language was significant, indicating that the differences between the categories were not the same across the two languages. Still, the difference in mean intensity between a stressed long and short vowel was 2.19 dB in Yup'ik and 3.15 dB in Alutiiq, while the difference between a stressed and unstressed short vowel was 1.78 dB in Yup'ik and 1.03 dB in Alutiiq. In short, the differences for intensity between the stress-length categories were more consistent across the two languages than the differences for duration. In Figure 2, however, Alutiiq intensity values appear overall lower than those of Yup'ik. Pairwise comparisons confirmed this for stressed long vowels (β = -9.1; *SE* = 0.332; *df* = 4502; *t* = -27.360; *p* =

<.0001), stressed short vowels (β = -10.1; *SE* = 0.227; *df* = 4505; *t* = -44.374; *p* = <.0001), and unstressed short vowels (β = -9.7; *SE* = 0.212; *df* = 4506; *t* = -45.830; *p* = <.0001).

3.3. F0

The maximum f0 model for Yup'ik contained only the stress-length distinction and IP finality as fixed effects. The difference between a stressed long vowel and a stressed short vowel was not significant (β = -0.65611; *SE*= 0.51476; *df* = 3.02931; *t* = -1.275; *p* = 0.291437). The difference between a stressed and unstressed short vowel was, with unstressed short vowels being lower (β = -1.51746; *SE* = 0.157; *df* = 2077.69558; *t* = -9.665; *p* = <2.00e-16). This indicates that f0, unlike duration and intensity, was only associated with stress and not with length.

For Alutiiq, the model contained the stress-length distinction, distance from the left edge and the presence of a coda as fixed effects. Stressed long vowels were significantly higher in f0 than stressed short vowels (β = 1.0538; *SE* = 0.1938; *df* = 2016.7382; *t* = 5.4376; *p* = 6.05e-08), and unstressed short vowels were significantly lower than stressed short vowels (β = -0.4755; *SE* = 0.1416; *df* = 2008.265; *t* = -3.3586; *p* = 8.00e-04).

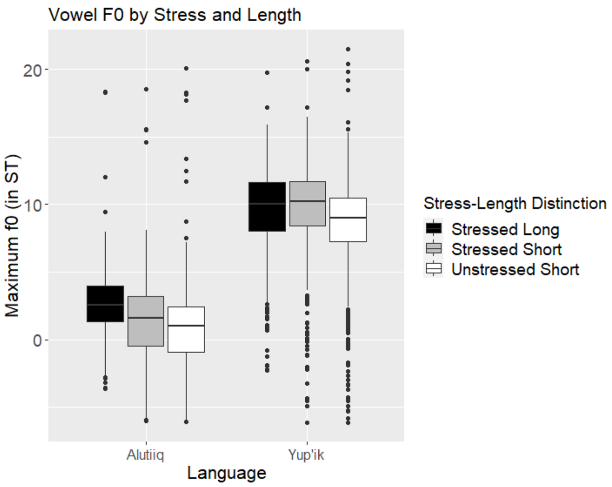

Figure 3: Boxplot of the maximum f0 of vowels by the stress-length distinction in Alutiiq and Yup'ik.

Figure 3 resembles the intensity figure more than the duration figure. However, in Yup'ik the non-significant difference in f0 between long and short stressed vowels was -0.04 ST, where the stressed short mean was slightly higher, while the difference between the same two categories in Alutiiq was larger, at 1.2 ST. Meanwhile, the difference between a Yup'ik stressed and unstressed short vowel was 1.47 ST, while the same difference in Alutiiq was only 0.52 ST. Modelling confirmed a significant interaction between the stress-length categories and language for f0. Pairwise comparisons showed that, like duration and intensity, Alutiiq vowels were significantly lower than their Yup'ik counterparts (stressed long: β = -6.52; *SE* = 0.231; *df* = 4271; *t* = -28.224; *p* = <.0001; stressed short: β = -7.70; *SE* = 0.161; *df* = 4253; *t* = -47.78; *p* = <.0001; unstressed short: β = -6.91; *SE* = 0.152; *df* = 4244; *t* = -45.606; *p* = <.0001).

4. DISCUSSION AND CONCLUSION

Table 1 summarizes the results of the acoustical analyses of Yup'ik and Alutiiq stress. Interestingly, despite the ways in which the two languages' metrical systems diverge, they largely express stress and phonemic length via the same acoustic correlates. There are, however, some differences. Notably, unlike Alutiiq, Yup'ik does not reliably mark length via f0. In turn, the durational difference between long and short stressed vowels was much larger in Yupik than in Alutiiq. This is likely because of duration's high functional load in Alutiiq: not only does it communicate phonemic length and stress information, but it is also affected by compression and, according to the literature, ILT head lengthening.

Table 1: Summary of results: acoustic correlates of stress and phonemic vowel length.

	Stress Correlates	Length Correlates
Yup'ik	Duration, Intensity, Maximum f0	Duration, Intensity
Alutiiq	Duration, Intensity, Maximum f0	Duration, Intensity, Maximum f0

Nevertheless, both languages consistently distinguish three types of vowel: long, obligatorily stressed vowels and short vowels that may be either stressed or unstressed. These distinctions are preserved even in cases of compression, contra previous descriptions of Alutiiq [5]. Our results are in line with a previous study of vowel duration in Central Siberian (St. Lawrence Island) Yupik [28], which found similar differences between long, stressed short and unstressed short vowels. Together, these studies show that the ternary stress-length distinction appears to be a stable factor in Yupik languages, despite the diversity of metrical systems.

Many questions remain surrounding the Yup'ik and Alutiiq metrical systems. This study represents the first acoustical examination and comparison of metrical expression in Yup'ik and Alutiiq, opening the door for further investigation into these intricate systems. Future work will determine acoustic correlates of Alutiiq additional lengthening and tone.

5. REFERENCES

[1] S. Jacobson, "Siberian Yupik and Central Yupik prosody," in *Yupik Eskimo prosodic systems: descriptive and comparative studies*, 1985, pp. 25–45.

[2] S. Jacobson and A. Jacobson, *A practical grammar of the Central Alaskan Yup'ik Eskimo language: with Yup'ik readings*. Fairbanks, AK: Alaska Native Language Center, 1995.

[3] A. C. Woodbury, "The postlexical prosody of Central Alaskan Yup'ik," Austin, TX, 1995.

[4] M. Mithun, "Prosody, grammar, and discourse in central Alaskan Yup'ik," p. 222, 1996.

[5] J. Leer, "Prosody in Alutiiq," in *Yupik Eskimo prosodic systems: descriptive and comparative studies*, 7th ed., M. Krauss, Ed. Fairbanks, AK: Alaskan Native Language Center, 1985, pp. 77–134.

[6] M. Hewitt and J. Ann, "Binarity and ternarity in Alutiiq," in *Arizona Phonology Conference Vol. 4*, 1991.

[7] M. Hewitt, "Deconstructing foot binarity in Koniag Alutiiq." University of British Columbia, Vancouver, BC, Feb. 1994.

[8] C. Rice, "Stress assignment in the Chugach dialect of Alutiiq," in *Proceedings of the Chicago Linguistic Society*, 1988, pp. 304–315.

[9] V. Martínez-Paricio and R. Kager, "Metrically conditioned pitch and layered feet in Chugach Alutiiq," *Loquens*, vol. 3, no. 2, 2017, doi: 10.3989/loquens.2016.030.

[10] J. Leer, "The Phonology of the Kenai Peninsula Dialect of Chugach Alutiiq." Alaska Native Language Center, Fairbanks, AK, 1994.

[11] A. C. Woodbury, "Eskimo and Aleut languages," in *Handbook of North American Indians*, vol. 5, D. Damas, Ed. Smithsonian Institution, 1984, pp. 49–63.

[12] B. Hayes, *Metrical stress theory: principles and case studies*. 1995.

[13] J. Leer, "Evolution of prosody in the Yupik languages," in *Yupik Eskimo prosodic systems: descriptive and comparative studies*, vol. 7, M. Krauss, Ed. Fairbanks, AK: Alaskan Native Language Center, 1985, pp. 135–158.

[14] J. Leer, *Yupik Eskimo Prosodic Systems: Descriptive and Comparative Studies*. 1985.

[15] J. Leer, "Toward a metrical interpretation of Yupik prosody," *Yupik Eskimo Prosodic Systems: Descriptive and Comparative Studies*, pp. 159–173, 1985.

[16] N. Gabas, "Phonetic correlates of stress in Yup'ik," *Prosody, Grammar, and Discourse in Central Alaskan Yup'ik, Santa Barbara Papers in Linguistics, vol. 7*, pp. 17–36, 1996.

[17] P. Afcan and E. Hofseth, *Napam cuyaa*. Fairbanks: Eskimo Language Workshop, University of Alaska, 1972.

[18] A. Blue, *Cungauyaraam Qulirai: Annie Blue's Stories*. Fairbanks, AK: Alaskan Native Language Center, 2007.

[19] D. Tabios and S. Meganack, *Sugcestun unigkuat: stories in the Sugcestun language from the villages of English Bay and Port Graham*. Fairbanks, AK: Division of Alaska Native Languages, Center for Northern Educational Research, 1972.

[20] "Alaska Native Language Archive." https://www.uaf.edu/anla/ (accessed Nov. 25, 2022).

[21] P. Boersma and D. Weenink, "Praat: doing phonetics by computer [Computer program]. Version 6.1.10," *retrieved 23 March 2020*. 2020.

[22] A. Arnhold, "Duration, Intensity, F0 Measurement Script," *https://sites.ualberta.ca/~arnhold/scripts/OnlyMeasurements/MeasureIntensityDurationF0minF0maxF0contourpoints.praat*, 2018.

[23] R. H. Baayen, D. J. Davidson, and D. M. Bates, "Mixed-effects modeling with crossed random effects for subjects and items," 2006.

[24] D. Bates, M. Maechler, B. Bolker, and S. Walker, "lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7, http://CRAN.R-project.org/package=lme4.," *R package version*, 2014.

[25] D. Bates, M. Mächler, B. M. Bolker, and S. C. Walker, "Fitting linear mixed-effects models using lme4," *J Stat Softw*, vol. 67, no. 1, 2015, doi: 10.18637/jss.v067.i01.

[26] A. Kuznetsova, P. B. Brockhoff, and R. H. B. Christensen, "lmerTest Package: Tests in Linear Mixed Effects Models," *J Stat Softw*, vol. 82, no. 13, pp. 1–26, 2017, doi: 10.18637/jss.v082.i13.

[27] R. Lenth, "Package 'emmeans,'" *CRAN*, Sep. 2022.

[28] J. H. Koo and L. Badten, "Acoustic measurements of the 'fake' vowel length and degrees of vowel length in St. Lawrence Island Eskimo," *Phonetica*, vol. 40, no. 4, pp. 213–220, 1974.