TRIBRACH-SHAPED WORDS IN THE TRAGIC TIMETER

A. M. Devine and Laurence D. Stephens

I. INTRODUCTION

The special restrictions on syllables appearing in resolved positions have long been a major topic in Greek metrics, and justifiably so, since they are crucial not only for philologically exact descriptions but also for a proper understanding of the very nature of Greek metre. In this paper, we shall discuss one of these restrictions, namely the following rule governing tribrach-shaped words in the tragic trimeter:

> When a resolved longum is implemented by the final two syllables of a tribrach-shaped word, then the vowels of those two syllables are normally either in hiatus or separated by the consonant ρ only ($-\breve{V}\breve{V}(C)\#$ or $-\breve{V}\rho\breve{V}(C)\#$).

This rule represents the most important instance of what Sidney Allen[1] has termed the principle of minimal separation (because the separation between the two syllables (∅ or ρ) is assumed to be in some sense less than with consonants other than ρ). The rule involves the application of the principle of minimal separation to tribrach-shaped words located so that the last two syllables implement the resolved longum, i.e., located without "zeugma," to use Irigoin's[2] convenient term. For the sake of clarity and brevity, we shall sometimes use the symbol ⏑⏑⏑ to denote the linguistic entity of a tribrach-shaped word; ⏑⁀⏑⏑ to denote a tribrach-shaped word located with zeugma; and ⏑⏑⁀⏑ to denote a tribrach-shaped word located without zeugma (i.e., in the position to which the principle of minimal separation applies according to the above rule).

The principle of minimal separation in resolutions has implications in various areas of Greek scholarship. It has been used as a criterion in textual criticism (see below and, e.g., Euripides *Hippolytus* 1029). It has been used to provide a measure for the relative dating of Euripides' tragedies and for defining his *stilus severior*. But its most critical application is to an issue of metrical theory so fundamental that it concerns any reader of Greek verse: how are the metrical elements in the Greek metrical system to be defined, and how do they relate to independently existing categories of the language? This is the basic question in any analysis of metre, and it has, in one sense or another, divided metrists

[1] W. Sidney Allen, *Accent and Rhythm* (Cambridge 1973) 327.

[2] This term and its counterpart "coupe," which refers to the occurrence of word boundary preceding the resolved *longum*, were established by J. Irigoin in an important study, "Lois et règles dans le trimètre iambique et le tétramètre trochaïque," *REG* 72 (1959) 67–80.

Phoenix, Vol. 35 (1981) 1.

into two camps since ancient times. The issue is currently under debate; we can distinguish the position of traditional metrists, including ourselves, who have a strict requirement for a linguistic basis of metre, and the position of those for whom metrical elements originate in an externally motivated rhythmical pattern and syllables are selected to implement those elements on the basis of durational criteria having no comparably significant status in their language classification.[3] The principle of minimal separation, if valid, presents precisely the conditions that would corroborate this latter conception of metre and crucially weaken the traditional position. This is because, outside a theory such as that of Sidney Allen,[4] there would appear to be little phonological basis for the special status of minimally separated syllables, whereas the rhythmical-durational theory of metre seems to provide a ready framework for the direct explanation of the phenomena.

The principle of minimal separation has a long history. In 1812, in his treatment of resolutions in the fifth foot[5] of the iambic trimeter, August Seidler observed that *arses solutae* are normally filled by the initial syllables of a word (cp. Irigoin's "coupe"). For the exceptions to this rule, he proposed the principle of minimal separations as an explanation: "longe maiori eorum parti hoc est commune, ut in quinti pedis arsi vel vocales habeant *ια* sive *ιο* vel consonam *ρ*. Harum igitur litterarum pronuntiationem habuisse aliquid coniicias, unde communis regulae violatio commode veniam inveniret."[6] In 1832, Eduard Wunder noted another regularity involving resolutions: "magnopere sibi caverunt tragici, ne longam ita solverent, ut syllabae finales verbi praecedentis eius locum occuparent"[7] (cp. Irigoin's "zeugma"). To explain exceptions to this second regularity, Wunder likewise invoked the principle of minimal separation and proceeded to draw the logical consequences for the phonology of colloquial Attic: "Immo certum puto, syllabas *ια* hic, ut alibi saepe, pronuntiatione in unam longam fere coaluisse. . . . Sunt eius generis plura vocabula in *ιον*, *ιος*, et *ια* desinentia, quorum postremae syllabae me quidem iudice dubitari non potest quin vulgari sermone in unam contracta sint." Wunder appealed frequently to his "contraction" theory as a "magna excusatio" for various types of resolu-

[3]This second position is supported in one form or another by scholars such as Maas, Wifstrand, Irigoin, Snell, and most explicitly by West. See our comprehensive discussion and literature therein: "Preliminaries to an explicit theory of Greek metre," *TAPA* 107 (1977) 103–129.

[4]See discussion below, 25.

[5]Since the foot is a well-motivated structural unit in the iambic trimeter, there is no reason to avoid the term where appropriate. See our discussion in "Anceps," *GRBS* 16 (1975) 197–215.

[6]*De versibus dochmiacis tragicorum graecorum, pars posterior* (Leipzig 1812) 385.

[7]*Adversaria in Sophoclis Philoctetem* (Leipzig 1823) 31.

tions "cur nihil habeant offensionis" (24, 32). Nor did he limit it to hiatic sequences of vowels, but extended it even to disyllabic forms of τις: "Nam pronominis τις formas τινά et τινί sic fuisse pronuntiatas, ut unius fere syllabae instar essent" (24). Twenty years later the principle of minimal separation was invoked by Fix in a note on Euripides *Electra* 13: "plerumque etiam syllaba soluta vel solas vocales continet . . . vel in medio interpositam habet litteram ρ."[8] The reference is to tribrach-shaped words coinciding with the second or fourth foot (see n. 5). Now if the principle of minimal separation is to have any explanatory basis, it must lie in the realities of the language, and, accordingly, Fix too explicitly states: "Unde duas istas syllabas uno spiritu pronuntiatas fuisse colligi potest." Such, it seems, is the origin of the theory that abnormally located resolved syllables must either have vowels in hiatus or be separated by the consonant ρ only.

As has often been the case in the history of Greek metrics, an observation originally made for its value to textual criticism eventually finds its way into the literature devoted to the theory and analysis of Greek metre. (Porson's Bridge [see his note on *Hecuba* 343] is certainly the most celebrated example.) We may observe this process halfway complete in C. F. Müller's study of resolution in the tragic trimeter,[9] which is still a basic reference source today. Müller readily appeals to the principle of minimal separations as "excusing" a word boundary after a resolved longum in tribrachs in Aeschylus (16,25,76), Sophocles (37,76), and Euripides (44,71–72) in various parts of the line, and bases the principle on the phonological hypothesis that minimally separated syllables "quasi coalescere atque unius fere instar esse syllabae" (75). Müller has evidently developed the observation into a general principle governing the metricality of resolutions, even to the extent of applying it to what is merely a representative sample of pyrrhic-shaped words in third foot tribrachs in Euripides (59–60).

It is important at this point to eliminate a possible source of confusion. It may seem that the older literature sometimes suggests that the two syllables with minimal separation are actually reduced by some phonological process to a single syllable, which is certainly a phonological possibility. However, insofar as two minimally separated syllables may actually be so reduced, they no longer constitute a problem. For in this case there would no longer be a hypershort sequence of two syllables, but a single syllable, which by definition cannot be "separated," minimally or otherwise. In fact there would be no resolution at all. An actual reduction of two minimally separated syllables, however, is usually ruled out on a combination of requirements from phonology and scansion. Insofar as a

[8]T. Fix, *Euripidis Fabulae* (Paris 1843) 1. lxvii.

[9]*De pedibus solutis in dialogorum senariis Aeschyli, Sophoclis, Euripidis* (Berlin 1866).

postulated reduction would produce a sequence that scans at all, the result would have to be a single heavy syllable in all instances. However, only a fraction of vowel-vowel sequences are such that the phonological processes most likely to affect them would yield a single heavy syllable (i.e., contraction proper, rather than, e.g., synizesis or syncope, which would typically yield a light syllable in ⏑⏑⏑). Consequently, if there is to be a direct phonological motivation for the principle of minimal separation, it will have to be something other than reduction to a single syllable.

Proceeding to modern scholarship, we find that T. Zieliński[10] repeats Müller's observation that, in the case of tribrach-shaped words line initially, minimal separations are favoured particularly in Euripides' *stilus severior*. For Sidney Allen,[11] limited consonantal separation is a phonologically motivated rule of Greek prosody, a principled constraint as linguists would call it, applying to resolutions in the tragic trimeter, its effect varying from the exclusion of *muta cum liquida* (*positio debilis*) in all types of resolutions[12] to the strict preponderance of hiatus or intervocalic ρ only for resolutions without zeugma such as line-initial tribrachs and, much less frequently, abnormally located first paeon words. Sidney Allen explains the principle of minimal separation in terms of his stress theory: two final light syllables must have minimal separation if they are to constitute a disyllabic stress matrix. Sidney Allen's treatment of the principle of minimal separation is the most useful modern examination, and the explanation he offers is based on a comprehensive and fully articulated theory of Greek prosody.

In modern durational theory, the principle of minimal separation finds a ready explanation. It is simply assumed that two light syllables, when minimally separated, constitute a disyllabic sequence, the overall duration of which is less than that of two light syllables comparable in all respects except that of their separation. The minimally separated sequence is therefore taken to be hypershort and to constitute a separate durational category. The durational theory also assumes that word-final syllables are longer than comparable non-final syllables. It further employs the principle that the duration of any two light syllables is greater than that of a single heavy syllable; therefore resolutions exceed the "ideal value" of the *elementum longum* so that they are subject to special durational restrictions. The principle of minimal separation is explained as one of these durational restrictions: if the syllables implementing a resolution are the final syllables of a word, there is a tendency

[10]*Tragodoumenon libri tres* (Cracow 1925) 145.

[11](Above, n. 1) 317, 323, 327.

[12]But see L. D. Stephens, "The myth of the *lex de positione debili* and a fundamental question in metrical theory," *Phoenix* 29 (1975), 171–181.

for the added duration resulting from their word-final position to be compensated for by the decrease in duration resulting from a minimal separation. We believe that the above represents a coherent statement of the doctrine, although we have not seen it fully and explicitly laid out in the literature.

Two orders of assumptions are crucial to the durational interpretation of the principle of minimal separation just outlined: (1) phonetic, that a sequence of two minimally separated syllables is shorter than sequences of two syllables separated by any consonant other than ρ *ceteris paribus*; and (2), the fundamental metrical assumption, that such a difference in duration, if it exists, is metrically relevant. We have discussed the second assumption above (25). As regards the phonetic assumption, it is most important to realize that the presuppositions made about the duration of ρ and other consonants are certainly not automatically true or true by definition; in fact, they would require typological evaluation. For instance, let us consider the case of Norwegian. In this language *r* is described as a "post-alveolar vibrant"[13] having as its most frequent implementation "a flap," rather than the presumably longer trill as in Greek. Now, Finthof[14] measured the average duration of Norwegian consonants: in intervocalic position the rank order was, $s,f > r > m,n \geqslant l > v$ ($>$ means "longer than," $\geqslant$ means "longer than or equal to"). So we have in Norwegian a language in which *r* is by no means the shortest of the consonants, but in fact has greater duration than the nasals and *l*.

In any case, one should consider not only the consonant but the whole disyllabic sequence, since, as everyone knows, consonants influence, most importantly, the duration of preceding vowels: in Spanish, for example, vowels are reported by Navarro Tomás[15] as longer before *r* than before various other consonants.

Thus a durational explanation for the principle of minimal separation is not self-evident, but rests on assumptions about the pronunciation of Greek which may or may not be correct. (In fact, it is not even safe to assume that every disyllabic sequence with hiatus is by definition of shorter duration than the comparable sequence with an intervening consonant).

At all events, it is premature to discuss the explanation of the minimal separation phenomenon before that phenomenon has been substantiated and its motivating factors clearly analysed. This we shall attempt to do

[13]A. Vanvik, "A phonetic-phonemic analysis of Standard Eastern Norwegian," *Norsk Tidsskrift for Sprogvidenskap* 26 (1972) 119–164.

[14]K. Fintoft, "The duration of some Norwegian speech sounds," *Phonetica* 7 (1961) 19–39.

[15]T. Navarro Tomás, "Cantidad de las vocales accentuadas," *Revista de Filología Española* 3 (1916) 387–408.

for those cases subsumed under the rule cited at the outset, since tribrach-shaped words represent by far the largest unitary source of evidence for the phenomenon.

II. THE DATA

Previous scholars have been content with the claim that minimal separations are far more common in tribrach-shaped words without zeugma than would intuitively be expected. However, if the principle of minimal separation is to be subjected to any form of careful examination, then the numbers of minimal and non-minimal separations actually occurring will have to be counted for the various poets, and explicitly presented. Moreover, it is not sufficient to compare the figures for ⏑⏑⏑ with and without minimal separation in just those positions in which the principle of minimal separation is claimed to apply, namely occurrences without zeugma (⏑⏑͡⏑). By themselves, these figures tell us nothing about the validity of the principle of minimal separation, because no basis of comparison is provided. Even if the frequency of minimal separations in ⏑⏑͡⏑ substantially exceeded that of non-minimal separations (as is indeed always the case except in later Euripides), this would not prove the principle of minimal separation, since we do not know whether such a preponderance of minimal separations in ⏑⏑͡⏑ would occur naturally. Thus a meaningful test requires a comparison of the frequency of minimal separations in ⏑⏑͡⏑ with their frequency in ⏑͡⏑⏑. For it is only by such a comparison that we can measure the effect of the principle on the frequency of minimal separations. Accordingly, we have performed the required complete frequency count.

Before presenting the results of this count, let us make absolutely explicit the criteria and definitions involved in it. A word is counted as a ⏑⏑⏑ if, and only if, it is so scanned in the verse. In practice this means that, of the potentially tribrach-shaped words ending in a consonant, only those were counted which stood before a word beginning with a vowel in their actual occurrence in the stichos; and, of the potentially tribrach-shaped words ending in a vowel, only those were counted which stood before a word beginning with a single consonant or *levis* variety of *muta cum liquida* cluster. This procedure was necessary in order to achieve full parallelism between zeugma and non-zeugma positions, and falls in with previous practice, since a post-metrical-sandhi definition of ⏑⏑⏑ is made in all theories which posit a principle of minimal separation. Secondly, we have not excluded from the count tribrach-shaped words preceded or followed by a word of appositive status.[16] This procedure,

[16]See A. M. Devine and L. D. Stephens, "The Greek appositives: toward a linguistically adequate definition of caesura and bridge," *CP* 73 (1978) 314–328.

which is at least suspect on linguistic grounds, was chosen because it is the one adopted by most supporters of minimal separation theory[17]; furthermore, the evidence for the principle of minimal separation is at its strongest when ⏑⏑⏑ adjacent to appositives are not excluded, and we felt it only right to test the theory in its strongest possible form. Finally, instances of ⏑⏑́⏑ elsewhere than in line-initial position are very rare (particularly outside later Euripides); we have excluded them from our discussion. To have included them would have entailed the elaboration of a different model to test each different location, and for Sidney Allen they do constitute a separate class (non-postpausal). In any case, their numbers are statistically negligible.

Table 1 certainly supports the hypothesis that minimal separation is more common in positions without zeugma. The difference in the frequencies of minimal separations in positions with an without zeugma is statistically significant for Sophocles ($\chi^2 = 8.53$), Euripides *severior* ($\chi^2 = 24.75$) and for later Euripides ($\chi^2 = 4.29$); for Aeschylus, the sample was too small to produce a significant chi-square, but since the difference is in the same direction, we must grant it hardly constitutes evidence against the validity of the principle of minimal separation for Aeschylus.

The strongest case that can be made out for the principle of minimal separation is based on the evidence from early Euripides (it is precisely here that Zieliński calls attention to the principle). In Table 1 we have allowed the data to stand in its most compelling form by following Zieliński in excluding *Andromache* from the definition of the *stilus severior*, and by allowing that *Hippolytus* 1029 (line-initial ἄπολις) is an interpolation.

The remainder of Euripides' tragedies, however, present a different picture. Although, in absolute terms, syllables with minimal separation are no longer a majority in line-initial tribrach-shaped words, nevertheless the tendency to favour minimal separations in such words (though weaker than in the other samples) is still present and statistically significant. Thus, although the principle of minimal separation would never have been advanced on the basis of later Euripides alone, statistically it proves to be still operative, showing how important it is to make explicit statistical tests in metrical studies.

III. IDENTIFICATION AND ASSESSMENT OF CORRELATED FACTORS

The data we collected in section II and the statistical tests to which we subjected those data prove that minimal separations are more fequent

[17]Sidney Allen, of course, properly takes appositives into account in his theory.

TABLE 1

DISTRIBUTION OF MINIMAL SEPARATIONS

Aeschylus		Sophocles		Euripides *severior*		later Euripides	
⏑ ⏑́⏑	⏑́⏑ ⏑	⏑ ⏑́⏑	⏑́⏑ ⏑	⏑ ⏑́⏑	⏑́⏑ ⏑	⏑ ⏑́⏑	⏑́⏑ ⏑
WITH MINIMAL SEPARATION							
10 (62.5%)	28 (39%)	28 (62%)	56 (39%)	19 (90.5%)	20 (26%)	60 (47%)	254 (34%)
WITHOUT MINIMAL SEPARATION							
6 (37.5%)	43 (61%)	17 (38%)	86 (61%)	2 (9.5%)	56 (74%)	78 (53%)	487 (66%)

in ⏑⏑́⏑ than in ⏑́⏑⏑ in all three tragedians, significantly so in Sophocles and Euripides. But it would be quite mistaken to go on to suppose that the only explanation of this must lie in a direct preference on the part of the poets for minimal separations in ⏑⏑́⏑. That would be a premature conclusion.

Because of the ways language is structured, it is regularly the case that different linguistic factors are correlated, so that if one factor is increased in frequency, it is likely that a number of other factors will also be increased by automatic reflex.[18] So, in the case of the factor of minimal separation, we must determine what other factors are correlated with it. When we have collected the most important correlated factors, we must then devise a test to discover which ones the poet directly aims at and which follow along automatically (rather than jumping to the conclusion that the first factor noticed, namely minimal separation, must be the directly preferred factor).

The best place to conduct the search for factors correlated with minimal separation is just where the principle applies most strongly, namely in Euripides *severior*. Here are the instances of tribrach-shaped words in line-initial position (⏑⏑́⏑): *Hippolytus*: πότερον 276, πατέρα 460, 1404, πότερα 516, 1009; *Heracles*: πατέρα 219, πεδία 393, λόγια 405; *Medea*: πατέρα 10, 896, φυγάδα 273, πότερον 378, 697; *Alcestis*: πατέρα 16, 339, 647, ὄνομα 351, πότερα 520, 1051; *Rhesus*: πότερα 630, δόλια 894.

The following are the factors which appear most obviously to be more frequent than in tribrach-shaped words in other positions in the line:

(1) minimal separations between the penultimate and final vowels
(2) word-final vowels
(3) occurrence of disjunctive question markers (πότερον, -α)
(4) word-initial consonant, or, more precisely, the structure voiceless, unaspirated labial stop + vowel + unaspirated dental stop
(5) the lexical item πατήρ.

Since a test on all these factors would be enormously laborious, it is only reasonable for us to restrict our attention to those factors for which we could find an initially acceptable metrical hypothesis requiring preferential location as line-initial ⏑⏑́⏑. On these grounds factors (4) and (5) were eliminated.[19] Consequently, in the following tests, there will

[18] For instance, increasing the number of dative singulars in a sample thereby automatically increases the number of word-final iotas.

[19] In Euripides *severior* resolution is comparatively rare. Furthermore, at least in the case of tribrach-shaped words, the less common lexical items are avoided more than the central lexical items (e.g., πατέρα) and grammar forms (e.g., πότερον). This compositional strategy reflects a constant, basic need for the latter two categories of words, as opposed to the former category which is an avoidable luxury. The reader should remember that the theory of minimal separations is designed to explain not the frequency of minimal separation in the overall corpus of ⏑⏑⏑ in any particular styles of Euripides, but rather the difference in proportion of minimal separation in ⏑⏑́⏑ versus ⏑́⏑⏑.

be four variable factors: presence versus absence of factors (1), (2), and (3) above, and location as ⏑⏑́⏑ versus locations as ⏑́⏑⏑, and we shall be testing three hypotheses about their interrelationships.

The basic logic of the test of the principle of minimal separation for line-initial ⏑⏑́⏑ is quite simple. It amounts to determining whether the incidence of minimal separations is the result of direct relationship between factor (1) and location (which is just another way of saying that the poets choose minimally separated ⏑⏑⏑ for line-initial location), or whether it results indirectly and automatically from the location of factors (2) and/or (3) via a correlation between them and factor (1). Now, making this determination is the same thing as making a statistical evaluation of Hypothesis III below, which is the comprehensive alternative to all hypotheses invoking the principle of minimal separation. However, to make this procedure more intuitively informative, we will also evaluate two of the more interesting hypotheses invoking the principle of minimal separation. In this way it will be possible to see just how far off these two latter hypotheses are and how superfluous the addition of the principle of minimal separation to Hypothesis III is.

The three hypotheses are as follows:

I. Hypothesis of minimal separation—strong form. This hypothesis claims that minimal separations are selected in ⏑⏑́⏑ and that factors (2) and (3) are automatic reflexes.

II. Hypothesis of minimal separation—weak form. This hypothesis claims that minimal separations together with factor (3) are selected in ⏑⏑́⏑ and factor (2) is an automatic reflex.

III. Hypothesis of remaining factors. This hypothesis claims that factors (2) and (3) are selected in ⏑⏑́⏑ and, in clear contradistinction to both of the preceding hypotheses, that minimal separation is an automatic reflex.

Statisticians have developed a whole field of study devoted to testing the interrelationships of many different factors of the type that concern us here: it is known as Discrete Multivariate Analysis. The techniques of this field provide us with the explicit mathematical procedures to test our three hypotheses.[20] In broad terms, the procedure is to calculate the expected frequency of each combination of presence and absence of the factors that would result from the interrelationships posited on the different hypotheses. These estimates are then compared with the frequencies actually occurring in the texts by use of the chi-square test. On this basis it becomes possible to determine to what extent each hypothesis explains the data, and to pick the one which is actually correct.[21] The

[20]For comprehensive discussion, see Y. Bishop, S. Feinberg, and P. Holland, *Discrete Multivariate Analysis: Theory and Practice* (Cambridge, Mass. 1975).

[21]Readers conversant with the theory of hierarchical log-linear models will be interested in the explicit mathematical formulation of the three hypotheses. No second or higher

calculations typically involved in Discrete Multivariate Analysis are extremely complicated and time-consuming, so that almost always they must be performed on a digital computer; and indeed, in this case, they were performed by L. D. Stephens on the Stanford IBM 370/168 computer. The results are presented in Table 2. The statistical procedures actually adopted are outlined in the Appendix.

Table 2 is basically self-explanatory. Since each of the three relevant factors may be either present (+) or absent (−) and either occurring in line initial position (+) or occurring elsewhere (−), there is mathematically a total of 16 combinations of which 4 cannot occur because they involve the self-contradictory combination of the presence of πότερον together with the absence of minimal separation. Thus, for instance, the seventh line of Table 2 is to be read as follows: line-initial (tribrach-shaped words) that have a minimal separation but are not πότερον, -α and do not have a final vowel occur 6 times (in Aeschylus, Sophocles, and Euripides *severior*); Hypothesis I predicts that they should be used nearly 18 times, Hypothesis II over 11 times, and Hypothesis III over 5. The following line, by contrast, refers to the same word type located in non-initial position in the line: its occurrence in this location is in fact 47; Hypothesis I predicts 32½ occurrences, Hypothesis II predicts almost 39, and Hypothesis III predicts over 49.

It immediately emerges that Hypothesis III, which maintains that minimal separations are only a reflex, consistently gives estimates that are not only better than the other two hypotheses but also very close in absolute terms to the occurring frequencies. A chi-square test (penul-

---

order interactions are present. Hypothesis I thus corresponds to the following log-linear model:

$$(1)\ log_e F_{ijkl} = u + u_{1(i)} + u_{2(j)} + u_{3(k)} + u_{4(l)} + u_{12(ij)} + u_{13(ik)} + u_{14(il)}$$

where the variables are numbered in the same (left-right) order as given in Table II. Hypothesis II corresponds to model 2:

$$(2)\ log_e F_{ijkl} = u + u_{1(i)} + u_{2(j)} + u_{3(k)} + u_{4(l)} + u_{12(ij)} + u_{13(ik)} + u_{14(il)} + u_{24(jl)}$$

Hypothesis III corresponds to model 3:

$$(3)\ log_e F_{ijkl} = u + u_{1(i)} + u_{2(j)} + u_{3(k)} + u_{4(l)} + u_{12(ij)} + u_{13(ik)} + u_{24(jl)} + u_{34(kl)}$$

The log-linear notation succinctly summarizes the crucial differences between the two hypotheses postulating the principle of minimal separation on the one hand and the hypothesis of the remaining factors on the other: both of the former incorporate a non-zero term u_{14}, whereas on the latter $u_{14} = 0$. It was not necessary to posit an interaction between variables 2 and 3, i.e., $u_{23} = 0$ for all hypotheses.

TABLE 2

COMPARISON OF OBSERVED DATA WITH VALUES PREDICTED ON HYPOTHESES I, II AND III

Values of Factors					Frequency predicted on		
minimal separation	*πότερον, -α*	word-final vowel	line-initial	Observed Frequency	Hypothesis I	Hypothesis II	Hypothesis III
+	+	+	+	21	7.9383	17.1388	22.6508
+	+	+	−	4	14.4840	5.3041	4.4647
+	+	−	+	8	5.5150	11.9069	6.3509
+	+	−	−	5	10.0625	3.6849	4.5346
+	−	+	+	22	25.6951	16.4946	18.7851
+	−	+	−	48	46.8824	56.0623	49.0896
+	−	−	+	6	17.8513	11.4594	5.2670
+	−	−	−	47	32.5709	38.9485	49.8580
−	+	+	+	0	0	0	0
−	−	−	−	0	0	0	0
−	+	−	+	0	0	0	0
−	+	−	−	0	0	0	0
−	−	+	+	12	5.8333	5.8333	13.5640
−	−	+	−	37	43.1666	43.1666	35.4456
−	−	−	+	13	19.1666	19.1666	15.3820
−	−	−	−	148	141.8333	141.8333	145.6072
Goodness of fit					$\chi^2 = 57.2171$	$\chi^2 = 19.8562$	$\chi^2 = 2.1415$
Degrees of freedom					d.f. = 8	d.f. = 7	d.f. = 7

timate line of Table 2) shows that the difference between the estimates based on Hypothesis III and the actually occurring frequencies are well within the margin of chance deviation and statistically insignificant, whereas the discrepancies between the observed data and the estimates based on each of the other two hypotheses are so great that they cannot be due to chance. Therefore Hypotheses I and II must be rejected.

Let us be very clear about what has been established by this test. The failure of Hypotheses I and II means in effect that the high incidence of final vowels cannot be wholly due to automatic reflex from a principle of minimal separation, but that there is a genuine and independent preference for final vowels in ⏑⏑͡⏑ in the first foot. Furthermore, the excellent fit of Hypothesis III shows that the high incidence of minimal separations in ⏑⏑͡⏑ is accounted for as a reflex of the high incidence of final vowels and of πότερον, -α (both factors turned out to be necessary). Thus, it has been proved that the poets are not directly aiming at minimal separations in ⏑⏑͡⏑. What is really going on is a sort of chain reaction. The poets use forms of πότερον, -α and tribrach-shaped words ending in a vowel for line-initial position, and willy-nilly they get a high proportion of minimal separations, because, quite independently of their choice, all forms of πότερον, -α have minimal separation and tribrach-shaped words ending in a vowel have a high incidence of minimal separation. We have achieved a negative result eliminating a factor (minimal separation) that was previously supposed relevant, and a positive result in identifying those factors (word-final vowels, disjunctive question markers) that in fact are relevant.

What clearly remains to be done is to discover *why* the latter two factors are relevant. This represents the second step in the scholarly process of discovering the facts and then interpreting them. Moreover, in this particular case, there remains a slight possibility that the durationalist hypothesis could re-emerge, seizing on the factor of final vowels in ⏑⏑͡⏑, despite metrical sandhi, (which would tend to trivialize the theoretical significance of our results).

IV. EXPLANATION OF RELEVANT FACTORS

Our computer test shows that (as claimed by Hypothesis III) there is an independent preference for disjunctive question markers and for word-final vowels in line-initial ⏑⏑⏑. This preference combines with the high frequency of minimal separations in those two categories to account fully for the observed frequencies of minimal separations in ⏑⏑͡⏑. Thus, for each of the two factors, an explanation must answer two questions: (1) what is the reason for the high incidence of minimal separations in the respective categories? and (2) what is the reason for the respective categories to be preferred in line-initial ⏑⏑́⏑? In our discussion, we shall use numerical estimates to indicate to what extent the motives we have found provide a complete explanation, and to what extent other, undiscovered motives may apply.

Let us start with the factor of disjunctive question markers. Question (1): of course, every instance of πότερον, -α will by definition have a minimal separation. Question (2): the motive for preferring πότερον, -α in line-initial position lies in a combination of Greek word order and the principles upon which syntactic structures are arranged in the stichos. The rules of Greek word order tell us that disjunctive question markers tend to occupy clause-initial position; and the harmony between syntactic and metrical unit is strongest in stichomythia and noticeable everywhere. In order to see how completely this explanation accounts for the high incidence of πότερον, -α as line-initial ⏑⏑́⏑, let us examine the data from Euripides *severior*. There are 10 occurrences of πότερον, -α in Euripides *severior* in all positions in the line. The question we have to answer is how many of these may be expected to appear in line-initial position. In a sample of the *Alcestis* we found that 50% of the occurrences of πότερον, -α were in stichomythia and 50% elesewhere. In stichomythia πότερον, -α always occurs as the first word in the line in Euripides *severior*. In running trimeters in the same sample, πότερον, -α is normally the first word in the sentence or clause. The first word of a sentence or main clause is also the first word of a stichos in 72.5% of all instances. Consequently, of the 10 examples of πότερον, -α, five will be expected to occur in stichomythia as the first word of the line, and 72.5% of the remaining 5 (3.63) will be expected to occur as the first word of a stichos in running trimeters. Therefore we estimate that there will be 8.63 examples of πότερον, -α as line-initial ⏑⏑́⏑, a value very close indeed to the actually occurring frequency, which is 8.

We turn now to the factor of final vowels. First, question (1). The high incidence of minimal separation in ⏑⏑⏑ with final vowels is made very clear by the following figures for the overall vocabulary of tribrach-shaped words in each poet. (This data appeared in Table 2 undifferentiated by poet.) Of all tribrach-shaped words in Aeschylus, 69% of those ending in a vowel have minimal separation, whereas only 30% of those ending in a consonant have minimal separation. For the seven tragedies of Sophocles, the figures are 60% minimal separations for ⏑⏑⏑ ending in vowels and 35% for ⏑⏑⏑ ending in consonants. For the tribrach-shaped words in Euripides *severior*, the figures are 76% for final vowels and 13% for final consonants. Part of the explanation for these figures seems to lie in the morphology of the Greek language as used in tragedy. Apart from πότερον, -α, the tribrach-shaped words used in tragedy, however located, are in the vast majority nouns and adjectives, mostly in the nominative or accusative singular. The dominance of these cases is only to be expected,[22] and many nouns simply are not tribrach-shaped in their oblique cases. Of the tribrach-shaped nominative-accusative forms of nouns that end in a vowel, one common type is neuter plural -ια from -ιο-stems; while in the third declension accusative singular type with final -α, the lexical item πατέρα has by far the highest text frequency of any tribrach-shaped example. These two categories (which both have minimal separations) account for more than four fifths of all vowel-final ⏑⏑⏑ (excluding πότερον) in Euripides *severior*, whether they are located with or without zeugma. (It is interesting that this proportion is halved in later Euripides, where accordingly the correlation between final vowels and minimal separation decreases in strength).

There are two kinds of theoretically possible explanations for the high incidence of final vowels in line-initial ⏑⏖ (question 2). On the one hand, it might be assumed that final vowels are favoured in this position due to a direct metrical rule, of the same nature as the above discredited principle of minimal separation. On the other hand, one could argue that the incidence of final vowels is simply that which would automatically arise when Greek words are arranged into trimeters. Hypotheses of the latter type may be extremely simple or highly complex. A simple "compositional" hypothesis would be that the high incidence of final vowels is simply due to the high incidence of initial consonants in the following word, and that this consonant frequency has motivations other than the avoidance of hiatus. (Complex "compositional" hypotheses would seek to refer to a number of interacting compositional factors). Compositional hypotheses function as "null" hypotheses *vis-à-vis* those positing a direct metrical rule, particularly since any metrical hypothesis of more than minimal sophistication must entertain compositional factors. The characteristics of a "null" hypothesis are that it does not make the crucial additional assumption(s) defining its alternative hypothesis. In this sense we shall test the null hypothesis for the frequency of final vowels in line-initial ⏑⏖.

In a sample of 300 stichoi from Sophocles' *Ajax* in which there was a word boundary after the first (unresolved) *longum*, it was found that there were 230 cases not involving positional lengthening. Table 3 compares the proportions of initial vowel and consonant for the following word in this sub-sample with the proportions for words standing after line-initial ⏑⏖ in Aeschylus, Sophocles, and Euripides *severior*.

[22] It is a universal of human language that for any language having case distinctions, the frequency of the direct cases is always greater than that of the oblique cases. This is true even of languages where the number of oblique cases is greater (in paradigms) than the number of direct cases. See J. H. Greenberg, *Language Universals with Special Reference to Feature Hierarchies* (The Hague 1966) 37–38.

TABLE 3

COMPARISON OF WORD-INITIAL VOWELS AND CONSONANTS

	#C-	#V-
after ⏓-#	72.6%	27.4%
after ⏑⏖	66.2%	33.8%

Table 3 shows that words following line-initial iambic or spondiac words start with a consonant even more often than words following line-initial ⏑⏖; so there is no reason to assume that the incidence of initial consonants after ⏑⏖ is anything but normal. Since, in the case of ⏑⏖, for every following word-initial consonant, there will be a preceding word-final vowel,[23] it is evident that the high incidence of final vowels in line-initial ⏑⏖ is the automatic reflex of the normal incidence of a following word-initial consonant and not due to a special metrical requirement.[24]

In this section, we have tried to show that the relationships between the factors emerging from the Discrete Multivariate Analysis are simply what we should expect on the basis of well-established properties of metre and language. Purely by way of informal illustration, let us see how the factors proved relevant can generate almost all the minimal separations occurring in the sample in which minimal separations are most frequent in ⏑⏖, namely Euripides *severior* (21 instances of line-initial ⏑⏖, 19 minimal separations).

[23]This is, of course, because "positional lengthening" would produce an anapaest, which is excluded from consideration by definition. On positionally lengthened anapaests see our forthcoming note.

[24]Or rather, it will be provided it is a reasonable assumption that the salient compositional factors are comparable for lines with initial ⏑⏖ and for lines with initial iambic or spondaic words. The following considerations point to this conclusion. Firstly, the incidence of word-initial consonants after iambic and spondaic words at the beginning of the line is 33% greater than that required simply to avoid hiatus (of course, still in the sub-sample without positional lengthening). It follows that the incidence of word-initial consonants is increased beyond the requirements of the line-initial word and thus not entirely dependent on it. Secondly, there are two compositional factors that provide further support for the assumption that more often than not, where there is an intervening word boundary, the second foot influences the first and not *vice versa*. As anyone who has tried his hand at Greek verse composition knows, it is easier to shift a word into line-initial position than into any other position, since one does not have to worry about whether it begins with a consonant or a vowel. Moreover, fully 50% of words that begin with the second foot are either absolutely fixed in that position for metrical reasons or very difficult to move elsewhere for syntactic reasons. This leaves only 50% of the cases in which the second foot could potentially be accommodated to the first, and it turns out that in these cases too the proportion of initial consonants in the second foot word is roughly the same after ⏑⏑⏑ as it is after spondaic and iambic words.

Above we have shown how considerations of word order and of syntax and metre would lead us to project that the frequency of disjunctive question markers (*πότερον*, *-α*) would be 8.63 in Euripides *severior*, as against the observed 8. Since the incidence of minimal separations in these forms is 100%, the number of minimal separations contributed by this first factor will be 8.63. Turning now to the factor of final vowels, which we have seen is, in principle, simply a reflex of the incidence of initial consonants in the following word, we find that of the 13 remaining ⏑⏑́⏑, 12 end in a vowel and only one in a consonant. In the *severior* plays overall, as noted above, 76% of all ⏑⏑⏑ ending in a vowel, wherever they are located, have minimal separations. Thus we would expect 9.12 minimal separations contributed by final vowels (12 × 0.76). Final consonants contributed only 0.125 (observed 1), since the overall incidence of minimal separations in words ending in a consonant is only 12.5%. As we can see from Table 4, when we sum up the contributions of the various factors, the difference between what is projected and what actually occurs is very small. A similar application to the data from Sophocles gives us Table 5, where, by contrast with Euripides *severior*, we predict slightly more minimal separations than the number actually observed.

TABLE 4

Comparison of Projected and Actual Minimal Separations in Line-initial ⏑⏑́⏑: Euripides severior

Source	Predicted	Observed
πότερον, *-α*	8.63	8
-V#, -C#	9.245	11
Total	17.875	19

TABLE 5

Comparison of Projected and Actual Minimal Separations in Line-initial ⏑⏑́⏑: Sophocles

Source	Predicted	Observed
πότερον, *-α*	14.22	14
-V#, -C#	15.6	14
Total	29.82	28

V. CONCLUDING REMARKS

Our analysis of the principle of minimal separation has reached the following conclusion: granted that the phonology, morphology, and syntax of the Greek language are the way they are, simply observing the traditional rules of tragic prosody and metre will automatically generate the required number of minimal separations in line-initial tribrach-shaped words. Since what is automatic is by definition not due to an independent principle. there can be no such thing as a "principle of minimal separation" and minimal separations are metrically irrelevant. So scholars will have to look elsewhere if they wish to substantiate the concept of minimal separation in phonetic terms or as a phonological class.

In this paper we have seen how a seemingly straightforward interpretation of an interesting phenomenon in the tragic trimeter can have profound consequences for the theory of metre; we have also seen how an adequate analysis and explanation of the data require complex and above all explicit argumentation and statistical methods. Fortunately, the results of all this *oleum et opera* extend beyond the immediate question of the principle of minimal separation, for all its theoretical implications, to a simple yet important moral. Metre is a system of many interacting factors and tendencies, which on occasion give rise to *prima facie* statistical anomalies. But before invoking his favourite *deus ex machina*, be it duration or stress, the metrist would be well advised to satisfy himself that the phenomena are not merely the result of the normal functioning and complex interaction of the two structured systems that are language and metre.

Stanford University

Appendix

Estimating the Predicted Frequencies

Each of the three hypotheses discussed in section III concerning the relationship between the four factors corresponds to an explicit mathematical model. Each of these models makes quantitative predictions about the frequencies with which tribrach-shaped words should take on the various combinations of factor values if the structural relations between the factors posited in the respective models are true. These predictions are estimated from various marginal sums of the observed frequencies (i.e., sums over the values of one or more factors). The following is a brief and informal description of the method for obtaining these estimates.

We must begin by introducing some notation. We shall refer to each of the fully specified tribrach-shaped words in the column "observed frequencies" of Table 2 by four subscripts: i refers to the value of the first factor ($\pm$ minimal separation), j to the value of the second ($\pm$ πότερον), k to the third ($\pm$ final vowel), and l to the fourth ($\pm$ line-initial). Thus x_{ijkl} represents any entry in the table, and when i, j, k, l are all $+$, x_{++++}, refers to the first entry. E_{ijkl} will be used to refer to the estimate of the frequency predicted by the model in question. Let us now consider the simplest hypothesis possible, namely that all four of the factors are independent of each other. This hypothesis means that the proportion of tribrach-shaped words having either value of any one of the factors will be the same, no matter what the values of the other three factors may be. The proportion of tribrach-shaped words having value i of variable one is simply the sum of the observed frequencies of all the tribrach-shaped words for which the value of the first factor is i divided by N, the total number of tribrach-shaped words: thus we must sum over the values of factors j, k, and l:

$$(1) \quad \frac{\sum_{j,k,l} x_{ijkl}}{N}$$

and similarly for the other factors. The frequencies expected on this independence model are obtained simply by multiplying together the proportions for each of the factor values times the total number of tribrach-shaped words:

$$(2) \quad E_{ijkl} = N \cdot \frac{\sum_{j,k,l} x_{ijkl}}{N} \cdot \frac{\sum_{i,j,l} x_{ijkl}}{N} \cdot \frac{\sum_{i,k,l} x_{ijkl}}{N} \cdot \frac{\sum_{i,j,k} x_{ijkl}}{N}$$

Of course, we already know that this simple model is not correct.

Unfortunately the predictions, E_{ijkl}, of the other models cannot be derived so simply, but perhaps an intuitive idea of the procedure can be gained from the following considerations. In the model for independence of all factors, the predictions for the frequencies of the combinations of factor values required only the overall proportions of each individual factor value as observed. However, for any set of factors that are correlated with each other, this information will no longer be adequate: the estimates E_{ijkl} will have to be based on information concerning the frequencies with which the correlated factors combine. Accordingly one must examine the hypothesis one wishes to test in order to determine the largest number of other factors with which each given factor is posited to be correlated. The estimates will then use the observed data for the frequencies of these highest order postulated combinations. Thus, e.g., in Hypothesis I above, factor four ($\pm$ line-initial) is posited to be associated only with factor one ($\pm$ minimal separation). The predicted frequencies of this hypothesis will, therefore, have to satisfy the constraints that the frequencies of the values of the factors posited as correlated must associate to the same extent as they do in the observed data. Accordingly the predicted frequencies of tribrach-shaped words having each combination of values of factors one and four are summed over all values of factors two and three, and that sum is constrained to equal the corresponding sum for the observed data, so that

$$(3) \quad \sum_{j,k} E_{ijkl} = \sum_{j\ k} x_{ijkl}$$

and similarly for the combinations of values of factors one and two, and of one and three. These estimates for the predicted frequencies, E_{ijkl}, thus become mathematical functions of linear combinations of the observed frequencies x_{ijkl}. The derivation of these functions is based on the theory of maximum likelihood estimation and is beyond the scope of this informal discussion. For the three hypotheses tested in this paper, simple closed expressions involving only the products of proportions (as in equation 2) cannot be obtained due to the mathematical nature of the likelihood equations. The method employed to calculate the E_{ijkl} is that of iterative proportional fitting, whereby the estimates are repeatedly adjusted to fit the constraints (such as equation 3) imposed by each hypothesis. For Hypothesis I, these are the steps in the estimation procedure. One starts out by setting all the estimates at 1:

$$(4) \quad E_{ijkl}^{(0)} = 1$$

The superscript 0 in parentheses refers to the number of the step in the procedure. These are adjusted in the following three steps. Since they are repeated in fixed order, we ennumerate as $3n + 1$, $3n + 2$, and $3n + 3$.

$$(5) \quad E_{ijkl}^{(3n+1)} = \frac{\sum_{k,l} x_{ijkl}}{\sum_{k,l} E_{ijkl}^{(3n)}} E_{ijkl}^{(3n)}$$

(since factors one and two are assumed to be correlated on this model)

$$E_{ijkl}^{(3n+2)} = \frac{\sum_{j,l} x_{ijkl}}{\sum_{j,l} E_{ijkl}^{(3n+1)}} E_{ijkl}^{(3n+1)}$$

(since factors one and three are assumed to be correlated)

$$E_{ijkl}^{(3n+3)} = \frac{\sum_{j,k} x_{ijkl}}{\sum_{j,k} E_{ijkl}^{(3n+2)}} E_{ijkl}^{(3n+2)}$$

(since factors one and four are assumed to be correlated).

Step $3n + 1$ brings the estimates in line with the observed data on the frequencies of the combinations of factors one and two. These adjusted estimates are then entered in step $3n + 2$ which further adjusts them to satisfy the constraint imposed by the correlation of factors one and three, and finally these newly adjusted estimates are entered in step $3n + 3$ to be adjusted for the final constraint. This cycle of steps is repeated to obtain any degree of accuracy desired.