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THE PHYSIOLOGY OF ANCIENT GREEK READING

INTRODUCTION

In the 1980s and 1990s, the medievalist Paul Saenger argued in several publications[1] that it was physiologically impossible for the ancient Greeks and Romans to read silently. His contributions revived an age-old controversy, which was first raised by Balogh in the early twentieth century and seemed to have been settled in 1968 by Knox, who concluded that silent reading was possible and not even unusual in antiquity.[2] Unlike his predecessors, however, Saenger did not base his arguments on the interpretation of the literary sources for ancient reading, but tackled the question from the point of view of cognitive psychology. He developed a detailed model of the processes involved in reading ancient *scriptura continua*, claiming that the very lack of word separation made vocal rehearsal necessary for the readers to recognize the words. Classical sources hinting at silent reading,[3] in his view, might rather refer to silent, or sub-vocal, oral reading – a sort of mumbling.[4]

Since their first appearance, Saenger's ideas have been met with partial acceptance or more or less harsh criticism by classicists. Svenbro, for example, acknowledges that *scriptura continua* hindered silent reading.[5] However, he also maintains that the Greeks were able to practise it because of a change of attitude towards the written word. Ingeniously, but questionably, he argues that silent reading implies a passive attitude for the reader, who relates to the text as the spectator in a theatre, and introduces as evidence for this new attitude literary and epigraphic allusion to such passivity (that is, 'speaking texts' that need no active

[1] Most recently in P. Saenger, *Space Between Words: The Origins of Silent Reading* (Stanford, 1997), 1–17.

[2] J. Balogh, 'Voces paginarum: Beiträge zur Geschichte des lautens Lesens und Schreibens', *Philologus* 82 (1927), 84–109, 202–40; B. Knox, 'Silent reading in antiquity', *GRBS* 9 (1968), 421–35. Cf. S. Werner, 'Literacy studies in classics: the last twenty years', in W.A. Johnson and H.N. Parker (edd.), *Ancient Literacies. The Culture of Reading in Greece and Rome* (Oxford, 2009), 333–82, at 337.

[3] A useful list in A.K. Gavrilov, 'Techniques of reading in classical antiquity', *CQ* NS 47 (1997), 56–73, at 70–1. Cf. P. Saenger, 'Silent reading: its impact on Late Medieval script and society', *Viator* 13 (1982), 366–414, at 370–6.

[4] For the distinction between 'silent oral reading' and 'true silent reading', see A.K. Pugh, 'The development of silent reading', in W. Latham (ed.), *The Road to Effective Reading: Proceedings of the Tenth Annual Study Conference of the United Kingdom Reading Association* (London, 1975), 110–19, at 114; id., *Silent Reading: An Introduction to its Study and Teaching* (London, 1978), 27–8. Cf. also P. Saenger, 'Physiologie de la lecture et séparation des mots', *Annales (HSS)* 44 (1989), 939–52, at 944–9, and id. (n. 1), 8–9.

[5] Cf. also C. Pébarthe, *Cité, démocratie et écriture: histoire de l'alphabétisation d'Athènes à l'époque classique* (Paris and Brussels, 2006), 21 and 73.

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'solicitation' from the reader, who is just supposed to 'listen').[6] Thomas accepts Saenger's views about the importance of interword spacing for the development of silent reading, but does not mention their final implications.[7] Raible adopts the whole model as it stands, only adding the claim that a text in *scriptura continua* could be read silently, if only one already knew it well.[8] Gilliard, on the other hand, rejects Saenger's ideas as being 'led astray by Balogh's work',[9] which he dismisses by opposing the same common-sense observations against the exclusivity of oral reading in antiquity that had already been presented by Knox: 'are we really to imagine that Aristarchus read aloud all the manuscripts of Homer he used for his edition?'[10] However, as Johnson points out, this argument is not appropriate, since 'our modern cultural construction of scholarly efficiency is predicated on silent reading'.[11]

In 1997 an article by Gavrilov appeared which dealt with the question of ancient reading and its physiology.[12] This article is totally independent from Saenger's publications, none of which are cited, and comes to the opposite conclusion, that is, that the ancients must have been able to read to themselves in order to be able to read out loud. Gavrilov's argument rests on the observation that 'the person reading aloud needs to be able to glance ahead and read inwardly selected portions of the following text', and that this ability is 'all the more necessary for reading aloud from texts written in *scriptio continua*'. Unfortunately, this conclusion is not supported by adequate experimental evidence: the psychological literature on which the argumentation is built is incomplete and was already out-of-date when the article appeared.[13] Secondly, reading to oneself is equated to reading *silently* to oneself, which is exactly what Saenger tried to prove impossible for readers of *scriptura continua* by discussing a remarkable amount of scientific literature. Johnson, however, uses Gavrilov's paper to argue against Saenger's cognitive model, setting the former's 'ability to use "science" to "prove" the conclusion he brings to the investigation' against the latter's. No real comparison is made between the two models: they are simply juxtaposed, and preference is accorded to Gavrilov's conclusions.[14] This refutation is unsatisfactory and hardly acceptable: to date, a real theoretically based discussion of Saenger's model is still missing.

[6] J. Svenbro, *Phrasikleia. An Anthropology of Reading in Ancient Greece* (Ithaca, NY and London, 1993), 160–86.

[7] R. Thomas, *Literacy and Orality in Ancient Greece* (Cambridge, 1992), 23.

[8] W. Raible, *Zur Entwicklung von Alphabetschrift-Systemen*. Is fecit cui prodest = *SHAW* 1991(1) (Heidelberg, 1991), 8.

[9] F.D. Gilliard, 'More silent reading in antiquity: *non omne verbum sonabat*', *JBL* 112 (1993), 689–94, at 693.

[10] Knox (n. 2), 421–2.

[11] W.A. Johnson, 'Toward a sociology of reading in classical antiquity', *AJPh* 121 (2000), 593–627, at 605.

[12] Gavrilov (n. 3).

[13] *Pace* Johnson (n. 11), 598. The works referenced by Gavrilov all appeared between 1927 and 1979.

[14] Johnson (n. 11), 598–600.

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SAENGER'S MODEL RECONSIDERED

Advances in experimental psychology in the last few years allow us to re-examine every point in Saenger's argumentation. In the present discussion, I will follow the structure of the latest version of Saenger's cognitive model (see n. 1).

(1) First of all, Saenger assumes that reading different types of script implies different cognitive processes.[15] Reading logographic scripts is a merely visual task, while alphabetic or syllabic scripts need the conversion of graphemes into phonemes, so that meaning can be accessed through phonology. This model can be described as a 'dual-route model'.[16] Logographic scripts activate the 'lexical route' and word recognition is merely orthographic. Printed words, after being visually input, are looked up as units in the mental orthographic lexicon. Alphabetic or syllabic scripts, instead, activate the 'non-lexical route' (or 'grapheme-phoneme correspondence route'), which needs prior 'phonological recoding': the visual input must be transformed into auditory information in one's mind before meaning can be accessed. Support for the dual-route model has been drawn from the fact that the aural and the visual recognition systems are physiologically separate in the brain (impaired subjects can independently lose or retain skills necessary for either process).[17]

An important corollary of the dual-route model is that logographic scripts can do without phonological recoding.[18] As a consequence, whereas readers of phonetic scripts should be able to read non-words using the non-lexical route (that is, by converting letters into the corresponding sounds), for readers of logographic script this would be impossible.[19] However, one must bear in mind that pure logography does not exist: all natural logographic scripts give clues to the phonetic value of the character. Most Chinese characters, for instance, are made up of two graphic elements, one encoding the meaning of the character (semantic radical), and the other encoding some phonetic information, normally corresponding to a syllable.[20]

[15] Saenger (n. 1), 1–3.

[16] M. Coltheart, K. Rastle, C. Perry, R. Langdon and J. Ziegler, 'DRC: a dual route cascade model of visual word recognition and reading aloud', *Psychological Review* 108 (2001), 204–56. Further references in F.K. Chua, 'Phonological recoding in Chinese logograph recognition', *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25 (1999), 876–91, at 876, and in D.L. Share, 'On the Anglocentricities of current reading research and practice: the perils of overreliance on an "outlier" orthography', *Psychological Bulletin* 134 (2008), 584–615, at 587.

[17] Such cases are described, for instance, in C. Papagno and L. Girelli, 'Writing through the phonological buffer: a case of progressive writing disorder', *Neuropsychologia* 43 (2005), 1277–87 or A. Caramazza and A.E. Hillis, 'Lexical organization of nouns and verbs in the brain', *Nature* 43 (1991), 788–90. Further references in Coltheart et al. (n. 16), 211; Saenger (n. 1), 3; D. Besner, D. Snow and E. Davelaar, 'Logographic reading: is the right hemisphere special?', *Canadian Journal of Psychology* (1986), 45–53, at 46–7.

[18] Chua (n. 16), 876, I.M. Liu, J.T. Wu, I.R. Sue and S.C. Chen, 'Phonological mediation in visual word recognition in English and Chinese', in P. Li, L.H. Tan, E. Bates and J.-L.O. Tzeng (edd.), *The Handbook of East Asian Psycholinguistics – vol. I: Chinese* (Cambridge, 2006), 218–24, at 224; J.R. Cho, 'The role of phonology in word recognition of Korean Hangul and Hanja', in C. Lee, G.B. Simpson and Y. Kim (edd.), *The Handbook of East Asian Psycholinguistics – vol. III: Korean* (Cambridge, 2009), 409–17, at 417.

[19] Chua (n. 16), 876–7.

[20] C. McBride-Chang and R.V. Kail, 'Cross-cultural similarities in the predictors of reading acquisition', *Child Development* 73 (2002), 1392–407, at 1393–4.

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Such phonetic components, however, do not have a consistent value. Therefore, they cannot be read as a syllabic or alphabetic grapheme would be, that is, by automatically converting them into mental auditory representations. Their correct recognition depends on the semantic radical, and must necessarily use the lexical, visual route. As a consequence, one would expect visual information to be sufficient for word recognition in Chinese, and phonological information should not interfere at all. However, experiments have shown that quite the opposite is the case, and that even in Chinese the lexical and the non-lexical routes work together. It has even been found that non-words, written as pseudologographs, can be pronounced.[21]

On the other hand, experiments have confirmed that alphabetic scripts elicit phonological recoding in both silent and, naturally, oral reading.[22] According to the dual-route model, word recognition, in this case, should depend only on the grapheme-phoneme correspondence. However, it has been found that lexical (merely visual) processes play a major role even in Italian, a language with transparent alphabetic orthography.[23] In conclusion, in all graphic systems, both alphabetic and logographic, lexical (visual/orthographic) and non-lexical (phonological) processes interact in word recognition,[24] with the lexical route leading the way. Things are not as clear-cut as Saenger believes.

(2) Saenger remarks that oral recitation is necessary for children to learn how to read alphabetic or syllabic scripts.[25] Phonetic script reading acquisition should presuppose phonological awareness, that is such 'purely spoken language skills' as

[21] Chua (n. 16), C.F. Hu and C.W. Catts, 'Phonological recoding as a universal process?', *Reading and Writing: An Interdisciplinary Journal* 5 (1993), 325–37; eid., 'The role of phonological processing in early reading ability: what we can learn from Chinese', *Scientific Studies of Reading* 2 (1998), 55–79; T. Guo, D. Peng and Y. Liu, 'The role of phonological activation in the visual semantic retrieval of Chinese characters', *Cognition* 98 (2005), B21–B34. Neurological data confirm both phonological recoding in Chinese silent reading – see G.Q. Ren, Y. Liu and Y.C. Han, 'Phonological activation in Chinese reading: an event-related potential study using low-resolution electromagnetic tomography', *Neuroscience* 164 (2009), 1623–31 – and its association with visual word recognition – C.Y. Lee, H.-W. Huang, W.-J. Kuo, J.-L. Tsai and J.-L.O. Tzeng, 'Cognitive and neural basis of the consistency and lexicality effects in reading Chinese', *Journal of Neurolinguistics* 23 (2010), 10–27.

[22] Most recently, P.F. de Jong, D.J.L. Bitter, M. van Setten and E. Marinus, 'Does phonological recoding occur during silent reading, and is it necessary for orthographic learning?', *Journal of Experimental Child Psychology* 104 (2009), 287–82; Ren et al. (n. 21), 1623 for further references. For the Hebrew script, see R. Frost and M. Kampf, 'Phonetic recoding of phonologically ambiguous printed words', *Journal of Experimental Psychology: Learning, Memory, and Cognition* 19 (1993), 23–33.

[23] G. Pagliuca, L.S. Arduino, L. Barca and C. Burani, 'Fully transparent orthography, yet lexical reading aloud: the lexicality effect in Italian', *Language and Cognitive Processes* 23 (2008), 422–33. In transparent orthographic systems each grapheme corresponds (more or less strictly) to one phoneme only.

[24] Cf. also A.M. Jacobs, 'The cognitive psychology of literacy', in the *International Encyclopedia of the Social & Behavioral Sciences* (Elsevier, 2001), 8971–5; K. Rastle, 'Visual word recognition', in M.G. Gaskell (ed.), *The Oxford Handbook of Psycholinguistics* (Oxford, 2007), 71–87. Prosodic information at word level is also part of the word recognition process, see J. Ashby and A.E. Martin, 'Prosodic phonological representations early in visual word recognition', *Journal of Experimental Psychology: Human Perception and Performance* 34 (2008), 224–36. Cf. M.J. Yap and D.A. Balota, 'Visual word recognition of multisyllabic words', *Journal of Memory and Language* 60 (2009), 502–29.

[25] Saenger (n. 1), 3–5.

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'the ability to perceive, segment and blend'[26] sounds, and should be causally linked to the acquisition of graphemic awareness (the ability to distinguish and recognize graphemes, or 'letter learning'). Accordingly, the ability to read an alphabetic script should only develop once the ability to correctly distinguish sounds from one another has been acquired. Experiments designed to prove this causal connection have generally been unsuccessful:[27] segmental awareness (the ability to isolate and segment sounds) only develops once graphemic awareness is acquired.[28] Such studies, however, assume that phonemes are the basic speech units of a language and equate *phonological* awareness with *phonemic* awareness (that is, the ability to segment sounds *as distinct phonemes*). This is a consequence, and not a prerequisite, of letter learning.[29] The development of phonemic awareness is not uniform across languages.[30] Conversely, certain levels of phonological awareness are universal among pre-schoolers: all children are able to isolate syllables (as opposed to phonemes) and, within syllables, to distinguish between onset (all that precedes the vowel) and rime (the vowel itself and any other following consonants). This ability is not exclusive to alphabetic or syllabic reading acquisition. In fact, it has nothing to do with the writing system and is substantial for reading acquisition even in such non-alphabetic orthographies as Chinese, where it assists children in learning and using the phonetic component.[31]

(3) Saenger argues that in the process of phonetic reading acquisition, children learn how to recognize the words holistically (as entire units) rather than synthetically (by putting together their phonetic components). If the boundaries between the words are not immediately detectable, children just start reading out loud, in order to access the meaning through the sound: reading unseparated text necessitates repeated focussing on short sequences of graphemes and might lead to a memory overload, which can only be overcome by the aid of vocal or sub-vocal activity, that is, muscular activity in the articulatory organs.[32] Saenger infers that the ancient

[26] A. Castles and M. Coltheart, 'Is there a causal link from phonological awareness to success in learning to read?', *Cognition* 91 (2004), 77–111.

[27] A. Castles, M. Coltheart, K. Wilson, J. Valpied and J. Wedgwood, 'The genesis of reading ability: what helps children learn letter-sound correspondences?', *Journal of Experimental Child Psychology* 104 (2009), 86–8. Cf. also S. Defior and P. Tudela, 'Effect of phonological training on reading and writing acquisition', *Reading and Writing* 6 (1994), 299–320.

[28] M. Carrillo, 'Development of phonological awareness and reading acquisition', *Reading and Writing* 6 (1994), 279–98.

[29] Cf. also M.H. Kosmidis, K. Tsakpini and V. Folia, 'Lexical processing in illiteracy: effect of literacy or education?', *Cortex* 42 (2006), 1021–7.

[30] It is more rapid in languages written in transparent orthographies and may not develop at all in languages written with a logographic system, see H. J. McDowell and M. P. Lorch, 'Phonemic awareness in Chinese L1 readers of English: not simply an effect of orthography', *TESOL Quarterly* 42 (2008), 495–513.

[31] U. Goswami, 'Phonological awareness and literacy', in the *Encyclopedia of Language and Linguistics* (Elsevier, 2006), 9.489–97; C. S. Ho and P. Bryant, 'Phonological skills are important in learning to read Chinese', *Developmental Psychology* 33 (1997), 946–51; Guo et al. (n. 21). Cf. McBride-Chang and Kail (n. 20), 1394.

[32] Saenger (n. 1), 5–6 suggests that readers would use the 'phonological loop' component of working memory: spoken language, or printed representations of spoken language (both alphabetic and pictographic), can be stored in short-term memory as phonological representations as long as they are rehearsed sub-vocally. See S.E. Gathercole, 'Working memory', in J.H. and H.L. Roediger III (edd.), *Learning and Memory: A Comprehensive Reference – vol. 2: Cognitive Psychology of Memory* (Oxford and San Diego, 2008), 33–51, at 35–5. For sub-vocalization,

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readers of *scriptura continua* must have experienced the same difficulties, and that it was impossible for them to read silently.[33]

As we have seen, in every graphic system word recognition is not entirely holistic: words are recognized as single meaningful units and analysed in their phonetic and graphic components at the same time. Indeed, it is their visual perception, which precedes recognition, that is generally assumed to be holistic.[34] In alphabetic script reading, the eyes move forward (in a movement called 'saccade') and stop ('fixation') by a 'preferred viewing location' (PVL), normally just left of the word centre,[35] bringing it to the centre of the visual field, where vision is most acute (foveal region). This movement is guided by word boundaries that lie in the parafoveal region (between 4° and 1° around the centre of vision), where vision is less acute and letter identification is harder,[36] but word length and shape are perceived.[37] In different graphic systems, guidance can be provided by different elements.[38] Contemporary Western scripts – Saenger is right – use interword spacing. Experiments have found that removing spacing in English results in a remarkable decrease in reading rate, affecting both word identification and eye movements: when spacing is absent, the saccades land on the beginning of words rather than on normal PVLs.[39] Conversely, in other writing systems spacing is simply redundant. If spacing is added to scripts that do not normally adopt it, the readers do not experience any positive effect. Instead, the novelty of spacing can

see A.N. Sokolov, *Inner Speech and Thought* (New York, 1972), 211; I. Taylor and M. Taylor, *The Psychology of Reading* (New York, 1983), 210–11.

[33] Saenger (n. 1), 7–9.

[34] E.D. Reichle, K. Rayner and A. Pollatsek, 'The *E-Z Reader* model of eye-movement control in reading: comparisons to other models', *Behavioral and Brain Sciences* 26 (2003), 445–526. For an alternative eye-movement model, see also R. Engbert, A. Nuthmann, E. Richter and R. Kliegl, 'SWIFT: a dynamical model of saccade generation during reading', *Psychological Review* 112 (2005), 777–813.

[35] Jacobs (n. 24), 8973; H. Winskel, R. Radach and S. Luksaneeyanawin, 'Eye movements when reading spaced and unspaced Thai and English: A comparison of Thai-English bilinguals and English monolinguals', *Journal of Memory and Language* 61 (2009), 339–51, at 339 for further references.

[36] K. Rayner and B.J. Juhasz, 'Reading processes in adults', in the *Encyclopedia of Language and Linguistics* (Elsevier, 2006), 10.373–8. There is some evidence that some phonological, orthographic and semantic information can even be retrieved from words that lie in the parafoveal area, which would allow parallel pre-processing of subsequent words. This seems to happen both in logographic and in alphabetic scripts. See S. Hohenstein, J. Laubrock and R. Kliegl, 'Semantic preview benefit in eye movements during reading: a parafoveal fast-priming study', *Journal of Experimental Psychology: Learning, Memory, and Cognition* 36 (2010), 1150–70.

[37] B.J. Juhasz, S.J. White, S.P. Liversedge and K. Rayner, 'Eye movements and the use of parafoveal word length information in reading', *Journal of Experimental Psychology: Human Perception and Performance* 34 (2008), 1560–79. Exterior letter pairs play a major role in word processing in spaced alphabetic scripts, most likely because of their position; see T.R. Jordan, S.M. Thomas, G.R. Patching and K.C. Scott-Brown, 'Assessing the importance of letter pairs in initial, exterior and interior positions in reading', *Journal of Experimental Psychology: Human Perception and Performance* 29 (2003), 883–93.

[38] M. Sainio, J. Hyönä, K. Bingushi and R. Bertram, 'The role of interword spacing in reading Japanese: an eye movement study', *Vision Research* 47 (2007), 2575–84, with a survey of previous studies.

[39] K. Rayner, M.H. Fischer and A. Pollatsek, 'Unspaced text interferes with both word identification and eye movement control', *Vision Research* 38 (1998), 1129–44 and M. Perea and J. Acha, 'Space information is important for reading', *Vision Research* 49 (2009), 1994–2000.

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disrupt reading fluency.[40] The readers' deep-rooted habits play a major role, and this must also have applied to the ancient readers of *scriptura continua*. There is no reason to infer that reading unspaced texts was as problematic for them as it is for modern Western readers.

As a contemporary benchmark for ancient Greek and Roman reading, the Liberian Vai syllabary,[41] brought in by Saenger,[42] is a poor choice. Conditions much more similar to the classical scripts are found in Thai instead. Thai script is an abugida, that is an alphabetic script where the vowels are obligatory but not totally independent signs and combine with the consonants in different positions (above or below, left or right). It does not use interword spacing. Experiments have found that the eye movements of Thai readers are exactly the same as those of English readers: the saccades land on the normal PVL, left of the middle of the words. Word segmentation is as efficient for readers of unspaced Thai as it is for readers of spaced English.[43] Therefore, there is no reason to assume that reading unspaced text is a particularly demanding cognitive task in itself, and Saenger's model must be rejected.

VISUAL SEGMENTATION CUES IN GREEK

As we have seen, spacing is not indispensable for reading alphabetic scripts, as long as other segmentation cues provide immediate information about word boundaries.[44] Ancient Greek *scriptura continua* must be no exception.

Scholars have proposed several candidates for this function. Raible, for instance, remarks that such later developments in the writing technique as the introduction of the accent and breathing signs and of a consistent punctuation system improved the readability of Greek texts: grave accents mark word endings and breathings mark word beginnings.[45] Accents, however, were only introduced by Aristophanes of Byzantium and were mainly used for poetry in dialects other than Attic. Breathings, too, only appear from the second century B.C.,[46] and the practice of drawing strokes over groups of letters to bind them together only started in late antiquity.[47] None of these devices was available to fourth-century Athenian readers, for example.

Classical sources, backed by the evidence of the earliest known Greek papyri, tell us that some sort of punctuation was already used in the first decades of that century.[48] In Athenian books, paragraphi were drawn under the first letters of the

[40] X. Bai, G. Yan, S.P. Liversedge, C. Zang and K. Rayner, 'Reading spaced and unspaced Chinese text: evidence from eye movements', *Journal of Experimental Psychology: Human Perception and Performance* 34 (2008), 1277–87; Sainio et al. (n. 38); Winskel et al. (n. 35).

[41] For a description and history of the Vai syllabary see S. Scribner and M. Cole (edd.), *The Psychology of Literacy* (Cambridge, MA, 1981), 31–4 and 267–70.

[42] Saenger (n. 1), 4.

[43] Winskel et al. (n. 35).

[44] Perea and Acha (n. 39).

[45] Raible (n. 8), 10–12.

[46] R. Pfeiffer, *History of Classical Scholarship from the Beginnings to the End of the Hellenistic Age* (Oxford, 1968), 180; E.G. Turner and P.J. Parsons (rev.), 'Greek manuscripts of the ancient world', *BICS* Supplement 46 (1987), 11–12.

[47] Turner and Parsons (n. 46), 8.

[48] Isoc. *Antid.* 59, Arist. *Rh.* 1407b18 and 1409a20. Cf. E.G. Turner, *Athenian Books in the Fifth and Fourth Centuries B.C.* (London, 1951), 6; Pfeiffer (n. 46), 179. Hyperides' mention of

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lines where a sentence ended or to mark a change of speaker in dialogues or dramatic texts. For the latter purpose, a dicolon could also be used.[49] It is self-evident that this type of punctuation is of a very limited relevance as a segmentation cue.

Johnson argues that segmentation could have been helped by the regular syllabic division of words at line ends in papyri columns.[50] Once again, this would help in isolating only a minority of words in a text. A much more promising approach is suggested, once again, by recent studies on Thai reading.

As we have seen, eye movement programming in Thai readers works in the same way as in Western readers of spaced alphabetic scripts. Words are identified immediately, and the saccades land on the normal PVL. It has been thought that the cues that allow such instantaneous segmentation are letter combinations. Interestingly, a statistical study on a corpus of 2,300 Thai words showed that 10 out of 74 characters occur at 76.4% of word endings and at 54.2% of word beginnings.[51] Moreover, sensitivity to the frequency of letters in initial and final positions – unconscious as it may be – has also been found in skilled English readers, and plays a role in word recognition.[52] We might, therefore, explore the possibility that specific combinations of letters worked as segmentation cues for ancient Athenian readers.

Thanks to such digital corpora as the *TLG-E*, we are able to test this hypothesis on substantial extents of text. Letter frequencies are not affected by text homogeneity, that is, they tend to be the same in text fragments or samples ('quasi-texts') as they would be in full, independent texts. This allows a great freedom in the definition of a corpus for statistical analysis.[53] For this study, Thucydides' *Histories*, all the works of Isocrates (excluding the fragments) and Plato's *Apology* have been chosen. The total word count amounts to 278,098. A first test calculated the relative frequencies of bigrams at initial (#*αα*, #*αβ* etc.) and final (*αα*#, *αβ*# etc.) positions, and of word-final-plus-word-initial combinations (*α*# #*α*, *α*# #*β* etc.). In another test, the occurrences of the following classes of letter combinations have been counted: (1) word-final-plus-word-initial; (2) bigrams in medial position (-*αα*-, -*αβ*- etc.); (3) initial and (4) final bigrams. Two-character words (#*αα*#, #*αβ*# etc.) have been counted separately (5). For every combination, the occurrences at word boundaries (1, 3, 4) have been summed up and divided by the total occurrences

παραγραφή (Hyp. *Dem*. fr. c Kenyon = a Whitehead) is preserved by Harpocration with the meaning of 'time-limit'. See D. Whitehead, *Hypereides. The Forensic Speeches* (Oxford, 2000), 454 and 471.

[49] Turner and Parsons (n. 46), 8–9; cf. W.A. Johnson, 'The function of the paragraphus in Greek literary prose texts', *ZPE* 100 (1994), 65–8.

[50] Johnson (n. 11), 611.

[51] Winskel et al. (n. 35), 349–50, citing a paper presented by R.G. Reilly, R. Radach, D. Corbic and S. Luksaneeyanawin at the 13th European conference on eye movements: 'Comparing reading in English and Thai – the role of spatial word unit segmentation in distributed processing and eye movement control' (2005).

[52] N.J. Pitchford, T. Ledgeway and J. Masterson, 'Effect of orthographic processes on letter position encoding', *Journal of Research in Reading* 31 (2008), 97–116; cf. E. Dąbrowska, *Language, Mind and Brain: Some Psychological and Neurological Constraints on Theories of Grammar* (Edinburgh, 2004), 25.

[53] P. Grzybek, E. Kelih and G. Altmann, 'Graphemhäufigkeiten (am Beispiel des Russischen). Teil II: Modelle der Häufigkeitsverteilung', *Anzeiger für Slavische Philologie* 32 (2004), 25–54, at 51; P. Grzybek, 'History and methodology of word length studies. The state of the art', in id. (ed.), *Contributions to the Science of Text and Language. Word Length Studies and Related Issues* (Dordrecht, 2006), 12–90, at 18.

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(1, 2, 3, 4). Two-character words are both initial and final bigrams at the same time, and would therefore be counted twice. In order to avoid this, their sum has been subtracted from both totals. The final formula of the frequency calculation is [(1) + (3) + (4) − (5)]/[(1) + (2) + (3) + (4) − (5)].

Designing a heuristic study of this kind presents several problems. First of all, we cannot take it for granted that the original Athenian texts looked exactly as they do in modern editions. If we can confidently assume that all the texts in the corpus were originally written or published[54] in the Ionic alphabet,[55] we do not know to what extent writing rendered such phonetic phenomena as assimilations and elisions.

In literary prose papyri, elided forms or *scriptio plena* are rarely used in a consistent way, even by the same scribe.[56] In prose inscriptions, elision is customary for bisyllabic prepositions by the fourth century; it applies sometimes to the compounds of δέ and is very unusual for τε and compounds. It can be found in cardinal numerals ending in α or ε, is exceptional for ἵνα and is normal for ὅσα and ὁπόσα before ἄν.[57] Assimilation in mono/bisyllabic and compound words is common in fourth-century Attic inscriptions and in the earliest papyri.[58] In the Derveni papyrus,[59] for instance, final -ν is often assimilated to initial consonants, but never at the end of a line or before λ. Since no rules can be consistently applied, we must make do with the text as is, with the awareness that the occurrences of some letter combinations might score lower than they would in fourth-century copies. This would be the case with μμ, μπ, μβ, μφ, μψ, γκ, γγ and γχ: final -ν, especially in articles, might have been assimilated to μ before labials or to nasal velar γ before velars.[60] Final -κ might have been assimilated to -γ before β, δ, λ, μ and ν, or to -χ before φ or θ.

Text divisions and punctuation would provide immediate information about word boundaries. However, as we have seen, it would be hard to reconstruct the exact placement of paragraphi in a fourth-century prose manuscript. Modern punctuation, evidently, is not always reliable for this purpose. Therefore, I have left out all punctuation information. This might result in some inaccuracy in the word-final-plus-word-initial combinations data. In the *TLG-E* texts I used, three full stops occur every 100 words. If we considered them as placeholders for ancient paragraphi, an acceptable three per cent margin of error would result. For analogous reasons,

[54] Thucydides seems to have used the Attic alphabet or, at least, a transitional Ionic-Attic alphabet. See E.C. Marchant, *Thucydides. Book II* (London, 1937), xxvii–xxviii; H.W. Litchfield, 'The Attic alphabet in Thucydides: a note on Thucydides 8.9.2', *HSPh* 23 (1912), 129–54.

[55] Pfeiffer (n. 46), 30.

[56] Turner and Parsons (n. 46), 8; cf. E. Mayser and H. Schmoll, *Grammatik der griechischen Papyri aus der Ptolemäerzeit. Band 1: Laut- und Wortlehre, I. Teil: Einleitung und Lautlehre* (Berlin, 1970), 132–5.

[57] L. Threatte, *The Grammar of Attic Inscriptions. Volume I: Phonology* (Berlin and New York, 1980), 419–23.

[58] Mayser and Schmoll (n. 56), 198–210; Threatte (n. 57), 579–640.

[59] The dialectal attribution, though, is still debated. See Turner and Parsons (n. 46), 92; M.S. Funghi, 'The Derveni papyrus', in A. Laks and G. Most (edd.), *Studies on the Derveni Papyrus* (Oxford, 1997), 25–37, at 26; G. Betegh, *The Derveni Papyrus. Cosmology, Theology and Interpretation* (Cambridge, 2004), 61–2; T. Kouremenos, G.M. Parássoglou and K. Tsantsanoglou, *The Derveni Papyrus* (Florence, 2006), 15–17.

[60] There are no examples of -ν > -γ before ξ, see Mayser and Schmoll (n. 56), 205.

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I have preserved the traditional division of Thucydides' work and the titles of Isocrates' speeches. All the occurrences of *iota mutum* were read as iota adscripts.[61]

In the first test, the frequency of initial and final bigrams and of word-final-plus-word-initial combinations has been calculated. The sum of the occurrences of each bigram has been divided by the number of words in the corpus. The following table shows the ten most frequent bigrams in each position and the percentages of word boundaries they account for.[62] This test, of course, is less powerful than the second, in that it does not take into account in ternal bigrams.

#κα	7.84	αι#	9.84	ν# #ε	4.86
#το	6.17	ων/μ/γ#	8.40	ι# #τ	4.84
#τη	3.15	ον/μ/γ#	5.67	ν# #τ	4.36
#με	2.90	ις#	4.70	ν# #α	4.06
#τω	2.82	υς#	4.44	ς# #ε	3.59
#ου	2.76	ιν/γ#	4.31	ς# #τ	3.57
#δε	2.73	ας#	4.30	ς# #α	3.12
#πρ	2.55	εν/μ/γ#	4.11	ν# #ο	2.72
#πο	2.50	ην/μ/γ#	3.58	ν/γ# #κ	2.68
#τα	2.37	οι#	3.56	ν/μ# #π	2.63
Total	35.79		52.91		36.43

7.84% of the words start with κα, 9.84% end with αι, and in 4.86% of word sequences the first word ends with ν and the next starts with ε. Summing up the values of each column, we find that the ten most frequent bigrams at word initial position in Attic Greek account for 35.79% of all word beginnings. The ten most frequent bigrams at word endings account for 52.91% of all word ends, and the ten most frequent bigrams at word-final-plus-word-initial position for 36.43% of all word boundaries.[63]

Table 1 shows the results of the second test. The reading order for the table is columns first. The cells show the frequencies of letter combinations at word boundaries, resulting from the above formula, expressed as percentages. The frequency of κα, for instance, can be read at the intersection of column κ and row α, and scores 88.6%. The higher the frequency of a combination, the more often it occurs at word boundary rather than in medial position. It is not possible, however, to determine how high the frequency must be for an experienced ancient reader to instinctively consider a bigram as a reliable cue for segmentation. Analogously, it

[61] W. Clarysse, 'Notes on the use of the iota adscript in the third century B.C.', *CE* 51 (1976), 150–66. Cf. Mayser and Schmoll (n. 56), 95–8; K. Meisterhans and E. Schwyzer (rev.), *Grammatik der attischen Inschriften* (Berlin, 1900), 67; B.H. McLean, *An Introduction to Greek Epigraphy of the Hellenistic and Roman Periods from Alexander the Great down to the Reign of Constantine (323 B.C. – A.D. 337)* (Ann Arbor, 2002), 347.

[62] If assimilation applied, such sequences as ων#, ην# etc. would become ωμ# or ωγ# etc. Some final sequences ending in μ or γ already occurred in the corpus (in elision forms). However, they are too scarce to affect the percentage calculated for the non-assimilated sequences.

[63] These figures are not directly comparable with those given for Thai, since that study computed characters, not bigrams.

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TABLE 1: FREQUENCY OF LETTER COMBINATIONS AT WORD BOUNDARIES IN ATTIC PROSE

	α	β	γ	δ	ϵ	ζ	η	θ	ι	κ	λ	μ	ν	ξ	ο	π	ρ	σ	τ	υ	ϕ	χ	ψ	ω
α	**99.7%**	30.7%	65.9%	36.7%	***83.3%***	41.9%	**100%**	*24.1%*	42.8%	***88.6%***	48.4%	36.5%	62.1%	***15.1%***	*78.1%*	*70.3%*	***18.8%***	55.5%	55.9%	60.7%	41.6%	45.9%	**2%**	**99.5%**
β	***15.1%***				39.7%		48.2%		53.4%	***10.9%***	**0%**	**0%**	**100%**		*25%*		**8.3%**	52%		61.6%				65.2%
γ	38.6%		**0%**		36.3%		50.3%		43.1%	52.9%	**0%**		**100%**		***14.8%***		**2.6%**	**96.3%**		*28.6%*				55%
δ	65.5%	**0%**	**0%**		43.2%		57.7%		61.7%	64.8%			*71.6%*	**100%**	56.7%		59.8%	**96.4%**		39.5%				***80.9%***
ϵ	**99.4%**	30.9%	39.9%	*74.8%*	**92.4%**	***12.4%***	***83.7%***	*24.5%*	69.8%	*20.5%*	***14.8%***	43.4%	*75.0%*	***15.2%***	66.8%	48.1%	***18.7%***	*78%*	39.9%	49.5%	***17.8%***	*21.1%*	34.6%	**98.1%**
ζ	**2.6%**				***18.5%***		**100%**		**5.9%**				**100%**		*74.1%*		**100%**	**100%**		34%				*22.2%*
η	**98.8%**	***16%***	48.4%	***82.2%***	*76.3%*	*70.2%*	**100%**	***16.7%***	53.1%	***16.8%***	**8.8%**	65.6%	52.0%	**8.0%**	*21.9%*	**7.3%**	*23.3%*	67.4%	66.6%	44.8%	56.1%	*20.4%*	53.4%	**97.1%**
θ	63.2%				33.4%		**9.3%**		37.5%	***84.2%***	**0%**		*26.7%*		*24.3%*		**5.0%**	***10.1%***		***16.5%***	*23.4%*	**0.6%**		**3.9%**
ι	*76.2%*	60.5%	*29.1%*	*75.7%*	31.2%	**0%**	***86.1%***	**7.4%**	***84.9%***	*26.3%*	**5.5%**	***19.5%***	37.4%	**3.5%**	48.3%	36.5%	33.9%	*29.5%*	57.9%	64.5%	32.7%	***18.2%***	45.4%	**93.5%**
κ	41%		**0%**		***84.4%***		40.1%		50.9%	***13%***	**0%**		**100%**	**100%**	40.5%		39.6%	***84.9%***		*77.8%*				40.4%
λ	48.8%	51.9%	***85.0%***		34.3%		*29.8%*	**0%**	32.8%	*25.5%*	***10.8%***		**100%**	**100%**	***10.4%***	62.4%	**100%**	**97.5%**	**7.7%**	**9.3%**	*77.8%*	**3.1%**		*27%*
μ	49.6%		**0.1%**	**0%**	44.5%		48.6%	**0%**	56.1%	*29.1%*	**0%**	**0%**	**100%**	**100%**	*21%*		*25%*	***83.4%***	*27.3%*	30.6%		**0%**		***14.1%***
ν	65.1%		31%	**0%**	55.1%		*75.8%*	***13.7%***	67.5%	***18.3%***		*27.5%*	61.9%	**100%**	61.2%	35.1%	***19.3%***	**99.9%**	**0%**	32.9%	**0%**	**0%**		**94.2%**

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TABLE 1: CONTINUED

ξ	47.1%		***13.3%***		*76.6%*		***82%***		*70.4%*		**0%**		**100%**		***16.9%***		***10.4%***	**99.6%**		51.8%				*24.4%*
ο	**90.1%**	47.3%	**1.5%**	37.2%	38.3%	**0.2%**	**100%**	***12.7%***	*27.9%*	***18.0%***	***19.1%***	***17.9%***	42.8%	**9.9%**	67.7%	58.2%	**4.7%**	68.5%	64%	*26.6%*	*25.2%*	**4.6%**	**6.9%**	**97.4%**
π	***86.2%***				***85.7%***		**94.8%**		***80.2%***	36.2%	**0%**	**0%**	**99%**	**100%**	56.6%	**0%**	***81.8%***	***87%***		***89%***				33.8%
ρ	47.2%	*70.9%*	36.3%	***14.7%***	***19.1%***		*23.6%*	*22.9%*	**5.6%**	33.2%			**100%**		*25.2%*	**91.8%**	**2.7%**	**99%**	30.5%	**2.5%**	55.7%	***81.4%***		**9.4%**
σ	67.3%				65.5%		52.2%		68%	***82.8%***	**0%**		**98.5%**	**100%**	*70.9%*		30.1%	56.9%		*71.4%*				***81.7%***
τ	31.9%				55.1%		48.1%		***82.1%***	54.2%	**0%**		46.1%	**100%**	48.9%	**2.7%**	54.3%	59.8%	**0.4%**	**9.8%**				***16.4%***
υ	61.8%	***16.9%***	41.1%	**68.5%**	32.2%	***16.7%***	**92.4%**	***15.1%***	**99.8%**	44.1%	45.2%	47.4%	***88.0%***	**97.9%**	38.5%	***85.8%***	*21.9%*	***88.5%***	50.2%	**100%**	63.9%	*21.8%*	*75.0%*	**100%**
φ	47.4%				67.7%		*25.8%*		*76.1%*	*22.9%*	**0%**	**0%**	**100.0%**		***18.1%***		63.3%	***87.5%***		*77.4%*				68.3%
χ	***12.8%***		**0%**		61.9%		58.8%		39.7%	***80%***	**0%**		**100.0%**		36.5%		**3.6%**	43.3%		38%				62.7%
ψ	***14%***				*24.9%*		***10.2%***		55.8%			**0.4%**	**100.0%**		46.4%		55.6%	**100%**		42.6%				
ω	**96.8%**	**8.9%**	*28.2%*	*24.7%*	***13.4%***	56.7%	**100%**	***14.5%***	***18.8%***	***15%***	**5%**	**1.1%**	36.7%	*79.2%*	59.8%	*25.4%*	**7.4%**	68.8%	53.6%	37.1%	*27.0%*	36.5%	36.4%	69.6%

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TABLE 2: ALTERED FREQUENCIES OF LETTER COMBINATIONS AFTER ASSIMILATION

γγ	*79%*	μβ	56.7%	κλ	*23.8%*	ν/__velar never occurs
γκ	**90.8%**	μμ	*76.1%*	κμ	**0%**	ν/__labial never occurs
γλ	**91.4%**	μφ	48.6%	κν	***13.8%***	
γμ	**5.4%**	μψ	*25.5%*			
γν	31.5%					
γχ	*71.3%*					

is impossible to know how low a frequency must be in order to provide a cue *not* to segment a string. In the impossibility of experimental testing on native speakers of Attic, no definite thresholds can be set.

In Table 1 combinations scoring above 90% and below 10% are printed in bold. It is very likely that combinations scoring such very high or very low frequencies were perceived as cues for or against segmentation respectively. Combinations ranging between 80% and 90% or between 10% and 20% are printed in bold italics. Those ranging between 70% and 80% or between 20% and 30% are printed in italics, and those ranging between 60% and 70% or between 30% and 40% in plain black font. Combinations scoring between 60% and 40%, the least likely to provide any cue, are printed in grey. Table 2 shows the combinations that would have a different score if assimilation applies both at word boundaries and internally in prepositional compounds. Such sequences as γβ, γδ, χθ, χφ and μπ are not included in the table. Since their non-assimilated counterparts, (κβ, κδ etc.), when internal, only occur in compounds, the score of the assimilated combinations would be exactly the same as that of the assimilated ones.[64] Assimilation of final -ν in polysyllabic words has been included in the computation, even though it was very unlikely to occur.

Both tables show that several combinations *do* occur frequently or seldom enough to be regarded as reliable cues for or against segmentation. Out of 420 phonetically possible combinations

- 55 (13.1%) occur at or around word boundaries more than 90% of the time;
- 27 (6.43%) between 80% and 90%;
- 24 (5.71%) between 70% and 80%;
- 37 (8.81%) between 60% and 70%;
- 74 (17.62%) between 40% and 60%;
- 44 (10.48%) between 30% and 40%;
- 40 (9.52%) between 20% and 30%;
- 46 (10.95%) between 10% and 20%;
- 68 (16.29%) less than 10% of the time;
- 5 (λδ, λν, λψ, πφ and ωυ)[65] never occur.

[64] Cf. L. Lupaş, *Phonologie du grec attique* (The Hague and Paris, 1972), 63. The question arises whether ancient readers perceived prepositional compounds as single units or isolated the initial prepositions.

[65] It must be borne in mind that non-Attic words (foreign personal names or toponyms) occur in the corpus. Moreover, entire passages have some dialectal colouring. This is the case, for

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Summing up, 62% of the combinations occur either more than 70% or less than 30% of the time at word boundaries, and 81.29% more than 60% or less than 40%. If assimilation applies

- combinations that were strong cues against segmentation become strong cues for segmentation ($\gamma\gamma$: from 0 to 79%, $\gamma\kappa$: 0 to 90.8%, $\gamma\chi$: 0 to 71.3%, $\mu\mu$: 0 to 76.1%), mitigate their status of cues against segmentation ($\mu\psi$: 0.4% to 25.5%) or de facto lose their cue status ($\mu\beta$: 0 to 56.7%, $\mu\phi$: 0 to 48.6%);
- some combinations slightly increase their frequency at word boundaries ($\gamma\lambda$ +6.4%, $\gamma\mu$ +5.3%, $\gamma\nu$ +0.5%);
- some unassimilated combinations slightly decrease their frequency at word boundaries ($\kappa\lambda$ –1.7%, $\kappa\nu$ –4.5%);
- some unassimilated combinations do not occur anymore at word boundaries ($\kappa\mu$), or disappear completely (ν followed by velars or labials).

Overall, only 10 more combinations would fail to fall into the 0–30% and 70%–100% ranges, the most likely to provide cues for or against segmentation. If assimilation at word boundaries applied consistently throughout the texts, 59% of the 420 phonetically possible combinations would still have more than 70% or less than 30% of their occurrences at word boundaries, thus being good candidates as segmentation cues.

Even though, obviously, we cannot verify this hypothesis experimentally, the tests show that it is plausible that letter combinations could guide experienced readers of Greek *scriptura continua*.

CONCLUSIONS

Saenger's idea that ancient readers were not physiologically able to read silently rests on a cognitive model which, on closer analysis based on recent experimental literature, is no longer acceptable. *Scriptura continua*, as it stands, does not necessarily hinder silent reading. As the case of Thai shows, readers who are accustomed to unspaced alphabetic scripts perform exactly the same physiological and cognitive operations as the readers of spaced scripts. As a consequence, it is reasonable to assume that the same must have been the case with ancient Greek readers. Recent research suggests that, for Thai readers, certain combinations of characters, which are more frequent at word boundaries than at internal positions, substitute for interword spacing in providing the eye with immediate cues for word separation. The same is plausible for Attic Greek: about 60% of the 420 phonetically possible letter combinations occur either more than 70% or less than 30% of the time at word boundaries, providing either a cue for segmentation, or the opposite. Moreover, limited sets of bigrams account for a significant number of word beginnings, word endings and word-final-plus-word-initial positions. No physiological constraints prevented the Greeks from reading

instance, with Doric in the 'Melian dialogue' (Thuc. 5.84–116), see K. Maurer, *Interpolation in Thucydides*. *Mnemosyne* Suppl. 150 (Leiden, 1995), 46–7.

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silently: whether they did, and under what circumstances, is up to the cultural historian to determine.[66]

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[66] As Johnson (n. 11), 600 points out.

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