Why do word breaks speed reading?

Zofii Kaczmarek

Stuyvesant High School

Professor Denis Pelli, NYU, Mentor

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Abstract
Many attempts have been made to determine why spaces increase reading speed, but it has not yet been satisfactorily explained. It has been proposed that spaces guide eye movements, and that spaces clarify word boundaries and thus aid in word identification. I propose that spaces relieve crowding at the beginnings and ends of words. I manipulated text to test these ideas, and the resulting reading speeds are consistent with the idea that spaces relieve crowding, and inconsistent with the idea that spaces guide saccade programming.

Introduction

While spaces between words seem to us a necessity, spaces were not introduced to text until 400 AD, thousands of years after written language developed. Spaces are known to significantly increase reading speed,[1] and I look at why this is true. I investigate the function of spaces in text and how spaces play affect crowding.

Spaces have been suggested to serve many functions. For one, spaces have long been thought to help readers plan saccades. A saccade is the movement between fixations, when reader's eyes jump from one word to the next and no visual information is processed.[2] It was formerly believed that saccades, the movement of the eye from one fixation to the next, were "guided primarily by spaces between words."[3] However, a study by Epelboim, Booth, and Steinman (1994) found that the "number of saccades/line of text remained approximately the same in both spaced and unspaced texts." They concluded that spaces do not guide eye movements, and instead words do.[3]

A review of this article by Rayner and Pollatsek (1994) suggested that spaces define word boundaries and thus aid lexical access.[4] Still, in their earlier study (1982), when "spaces were filled with digits, these space fillers should have afforded reasonably good information about where words began and ended (in order to guide lexical access) but should have disrupted eye guidance because space between words was no longer present. We found that reading ... was slowed by about 40%; this suggests that the lack of space information itself (rather than not having information to indicate where the end of the fixated word was) is likely to be important in reading … In the conditions in which letters filled the spaces and hence lexical access was likely to be severely disrupted … reading was slowed by about 60%."[4] Recent work on crowding suggests that only similar objects crowd,[5] and while there is no test for similarity, most numbers are similar enough to letters to crowd them. Given this, the 40% decrease in reading speed when lexical access was unimpaired could be caused by lost letter information when the filler numbers crowded the letters.

I suggest that the main function of spaces is to provide relief from crowding at the beginnings and ends of words. Crowding is a phenomenon in which objects or features within an object appear to an observer to overlap and mix when they are in the observer's periphery and when they are within a certain distance from each other. This 'certain distance' is the *critical spacing*, described by the Bouma law.[6] The critical spacing varies with location in the visual field. It is negligibly small at fixation and, at more peripheral locations in the visual field, the critical spacing grows in proportion to eccentricity (distance from fixation). Thus, while reading, the letters in the word a person is fixated are uncrowded, but most of the rest of the page is crowded, because the letters are closer than the critical spacing. However, there is an exception. The letters at the beginnings and ends of words are exposed on one side, and this allows them to escape crowding, unless the word gap is still small than the critical spacing. However, that larger spacing from last letter of one word to first of the next, is twice as large as the spacing between letters in a word, so this critical spacing occurs twice as far in the periphery. Thus the space between words uncrowds the beginnings and ends of the next few words ahead of the one being read.

If the spaces are taken out, however, the final letters of the fixated word and the beginning letters of the following word would crowd each other. I hypothesize that, when spaces are removed, the crowding increases, and this is what slows reading.

I designed several conditions to text to test the above-mentioned ideas about the function(s) of spaces, and I asked subjects to read 10 short paragraphs each manipulated in one of the 10 following ways.

Condition 1: and the

This is the base condition; there is no manipulation to the text.

2: andthe

3: xandxthex

4: xandx xthex

5: xandxxthex

If spaces relieve crowding at both ends of each word, then crowding is increased for all of the above conditions. In condition 2, crowding is caused by adjacent letters now within the critical spacing of the fixated word. In conditions 3, 4, and 5, crowding is caused by the flankers (x's) introduced between/before-and-after words. This also means that, if spaces are what guide saccade programming, then these conditions impair saccade programming. That is, except condition 4, because there are spaces between the crowded words. If spaces aid lexical access, then lexical access impaired for these conditions, because word boundaries are obscured by the added letters. Again, except for condition 4, for which lexical access is only slightly impaired, because word boundaries (beginnings and ends) are made obvious by the spaces, and readers must only ignore the flankers.

6: øandøtheø

7: 7and7the7

8: ßandßtheß

In the above conditions, numbers and symbols, not letters, are used to fill the spaces. Crowding only occurs between like (*i.e.* similar) objects,[5] so I expect that 7 crowds letters less than ß (eszett), and ß less than ø (phi). If spaces aid lexical access, then lexical access is only slightly impaired by removing spaces in these conditions, because there is no confusion about the boundaries between the words and the flankers. If spaces guide saccade programming, then saccade programming is impaired for all three conditions because the spaces are not preserved. If readers are able to block out the flankers, and use them as one would spaces, saccade programming might be aided slightly. This may be easier for conditions 7 and 8, where the flankers extend above most letters.

9: xand xthe

10: andx thex

Rayner, Well, Pollatsek, and Bertera (1982) showed that information beyond the fixated word is used in reading, and when only the fixated word is presented (using eye-contingent display), reading slows by about 40%.[7] For clarity, let word N be the fixated word, and word $N + 1$ be the following word. Rayner and Pollatsek (1994) compared reading speeds when all the spaces to the right of word N were filled, and when the first space (between words N and $N + 1$) was preserved. They concluded that “although the absence of spaces to the right of word $N + 1$ plays some part in reading, the absence of the first space … is the primary space information used by readers of English."[4] This could mean that readers use the information following the fixated word to program the next saccade, or it could suggest that readers use information about word $N + 1$ to identify word $N + 1$ before actually fixating on it. If the first space is not preserved, the initial letter of the next word will be crowded. (Letter information as opposed to word shape information—see [8] for what information is used in reading: letters, word shape, and context.) If readers use the letter information of word $N + 1$, then adding a flanker to crowd the beginning of word $N + 1$, thus destroying the beginning letter information, should slow reading speed. The reduction in speed should be similar to the 40% decrease observed when only the fixated word is presented. And this should slow reading speed more than crowding the end of the following word does. Conditions 9 and 10 test this.

Results

Conditions 2 through 5 all had very similar effects on reading speed. In these four conditions, reading speed is diminished by about 33 – 38% of the base condition. What is interesting about this result is not how much reading was slowed, but that the effects are so similar. If spaces guide saccade programming, one would expect to see condition 4, in which spaces are preserved, to produce faster readings speeds than conditions 2, 3, and 5. Instead, condition 4 has the slowest average speed among them.

Considering conditions 6, 7, and 8, we see that conditions 6 and 8 have similar effects on reading speed, and condition 7 produced a significantly larger decrease in reading speed. It could be that ø's are more similar to letters than 7's and ß's, so they crowd the letters more, but I think it is more likely that 7's and ß's in conditions 6 and 8 provide clearer word boundaries, because their characters extend upward, above most letters. This suggests that spaces may have some role in aiding lexical access by clarifying word boundaries.

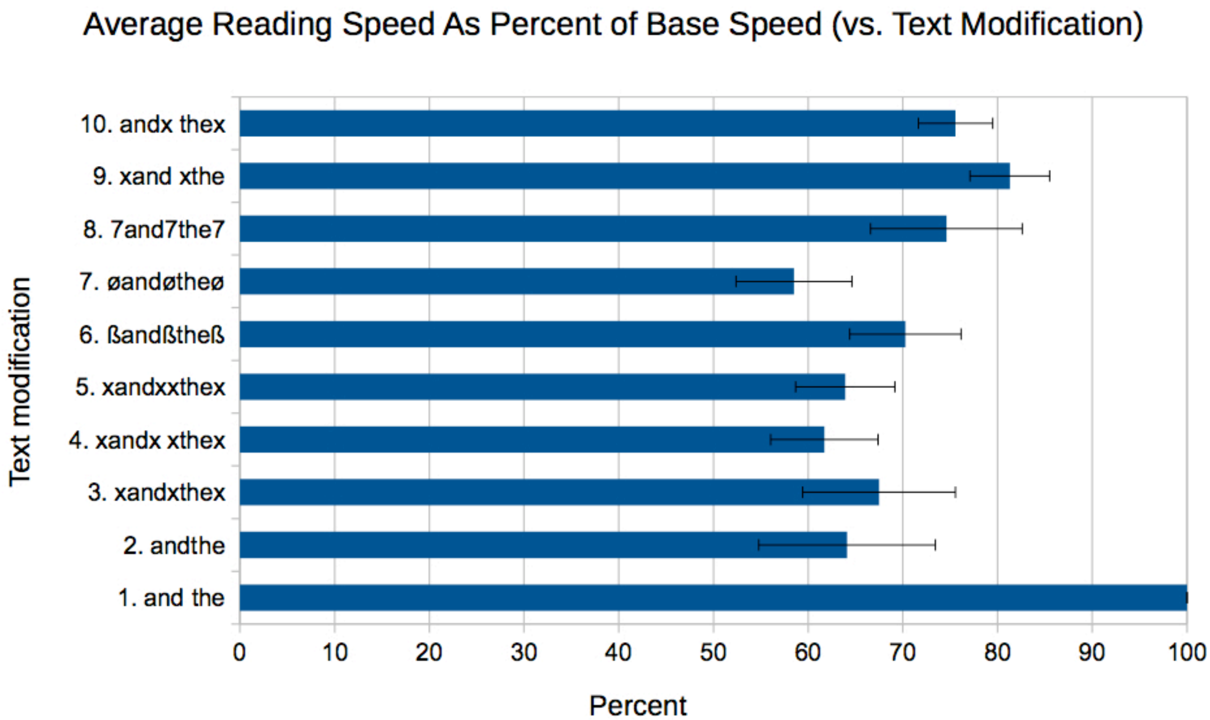

Figure 2: The reading speed of a subject was recorded for each of 10 conditions. The speeds were averaged across the 7 observers for each condition. The percent of the base speed that each condition's average speed represents is graphed here. In particular, the percents for conditions 2 through 5 are very similar, suggesting spaces do not guide saccades. The percent for condition 7 is smaller then for conditions 6 and 8, suggesting that some difference between ß and 7, and ø has an effect on reading speed. The percents for conditions 9 and 10 are very similar, suggesting that the beginnings of words are not relied on any more than the ends of words. Samples of all ten kinds of text are presented, for you to try, in the Appendix.

Finally, examining conditions 9 and 10, there is a small, insignificant difference in their effects on reading speed. Condition 9, for which flankers (x's) are added to the beginning of each word, slowed reading less than condition 10, for which flankers are added to the end of each word. It may be that letters at the beginnings of words are just as important and helpful in read as letters at the end of words.

The data are consistent with the idea that spaces relieve crowding, but not that spaces guide saccade programming. The results also suggest that spaces may help define word boundaries and increase reading speeds that way, but that conclusion depends on the assumption about what difference between ø's, 7's, and ß's is most relevant to this experiment.

Discussion

The conclusions to be drawn from these results can be broken up into three parts, comparing conditions 2 through 5, comparing conditions 6 through 8, and comparing conditions 9 and 10.

Conditions 2 through 5 are read at practically the same speed. They are equated for crowding, because the ends of the words are always flanked, but vary in whether they include a space, because condition 4 has a space and the rest don't. This shows that the presence of the space makes no difference when crowding is controlled. This contradicts the idea that spaces are specially good as markers for saccade programming. Spaces, per se, don't help. On the other hand, the consistently slow rate with equal crowding suggests that crowding is what slows reading in these conditions.

Four conditions (2,6,7,8) replaced the space by a symbol: x, ß, ø, 7. The short symbols x, ø, slow reading more than the tall symbols ß, 7. One possibility is that the shorter symbols are more similar by virtue of height. Another is that the tall symbols extend above most letters and are thus better markers for word boundaries and that this aids lexical access a bit.

Lastly, conditions 9 and 10 both slow reading to a similar extent, suggesting the beginning-letter information is just as important as the end-letter information for reading.

Conclusion

Spaces increase reading speed, but it was not clear why, despite several investigations. It has been proposed that spaces guide eye movements, and that spaces clarify word boundaries and thus aid in word identification and reading. I propose that spaces relieve crowding at the beginnings and ends of words. The effects of ten text manipulations on reading speed are consistent with the idea that spaces relieve crowding, and inconsistent with the idea that spaces guide saccade programming.

Materials & Methods

Text and Modifications

The texts were short sections of articles taken from articles published in the *New York Times*. ("Parsing of Data Led to Mixed Messages on Organic Food's Value," "A 700,000-Year Trip From Mars to Morocco," "Date Night at the Zoo, if Rare Species Play Along," "A Rogue Climate Experiment Outrages Scientists," "Joy Turns to Despair at National Zoo as Newborn Panda Is Found Dead," "New Planet in the Neighborhood, Astronomically Speaking," and "To Save Some Species, Zoos Must Let Others Die.") The *New York Times* was chosen as the source of text, because its articles are written for a wide audience and at a suitable reading level. The sections are between 200 and 310 words and were edited for clarity, so that they made sense despite being separated from the rest of the article. Texts were formatted so no lines would run off the screen when presented in any of the conditions.

A program written through MATLAB with the Psychophysics Toolbox produced the modified texts. Texts were modified filled by replacing every space with the symbol(s) and adding the appropriate symbol to the beginning and end of each line. The texts were presented through MATLAB on the same computer screen.

Subjects

Seven subjects participated. (Ages 17-49; 4 males; 3 females.) All had normal or corrected-to-normal eyesight and were fluent in English. All gave informed written consent. Parents of minors gave consent as well.

Procedure

The 10 modifications were randomly ordered for each subject, and the 10 texts to be subjected to each modification were also randomly selected. Subjects never saw the same text twice and were given the set of 10 trials once. Subjects were seated a comfortable, consistent distance from the text and given the following instructions: “Read as quickly you comfortably can while retaining comprehension and reading every word. Do not go back and reread text. You can click the mouse when you are ready to start, and again when you are finished. Afterwards, I will ask you a few questions to make sure you understood the text.” When the subjects finished reading, they were asked the questions related to the text they had just read. Whether or not they answered the questions correctly and the time they took to read the text (measured by the MATLAB program) were recorded. The reading speed for each subject-trial combination was calculated from the time to read the text and the number of words per passage. If a subject answered at least two questions (of the three) correctly, it was accepted that they had achieved a basic understanding of the text. However, if a subject answered at least two questions incorrectly, they were asked for the gist of the text. If the subject still did not demonstrate an understanding, they were given a new text with the same modification after the other trials were completed.

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Appendix

The following are ten text excerpts, one for each condition. Try reading them yourself and see how much your reading is slowed!

Condition 1:

A California businessman, Russ George, chartered a fishing boat in July, loaded it with 100 tons of iron dust and cruised through Pacific waters off western Canada, spewing his cargo into the sea in an ecological experiment that has outraged scientists and government officials. The entrepreneur, whose foray came to light only this week, even duped the National Oceanic and Atmospheric Administration in the United States into lending him ocean-monitoring buoys for the project. Canada's environment ministry says it is investigating the experiment, which was carried out with no government or scientific oversight.

Condition 2:

InautilityclosetatthebackoftheInsectariuminSt.Louisisevidenceofthegrowingpressureonzoos.Bob Merz,thezoo'smanagerforinvertebrates,pullsoutaclearkitchencontainerthatcouldbeusedforthe previousnight'sleftovers.Instead,itcontainslayersofmoistpapertowelcoveredinsnails,eachnobig gerthanapinkienail."Thisistheirhabitatnow,"hesaid.ThepartulasnailwasoncenativetoPacificislands aroundTahiti,butalargercarnivoroussnail,introducedtoattackotherpestsdestroyingcrops,has decimatedthepartulaaswell.

Condition 3:

xAxmeteoritexthatxlandedxinxthexMoroccanxdesertxlastxsummerxwasxejectedxfromxthex xsurfacexofxMarsx700,000xyearsxago,xaxnewxstudyxreports.xThexmeteoritexisxcomposedx xofxanxabundancexofxblackxglass,xwithxnoblexgasesxtrappedxinside.x"Basedxonxthexnoblex xgasxmeasurements,xwexcouldxcalculatexthexejectionxagexofxthexmeteorite,"xsaidxHasnaax xChennaouixAoudjehane,xanxastronomerxatxthexHassanxUniversityxinxCasablanca,x xMorocco,xandxthexstudy'sxfirstxauthor.x

Condition 4:

xBringingx xthex xsearchx xforx xanotherx xEarthx xaboutx xasx xclosex xasx xitx xwillx xeverx xget,x xax xteamx xofx xEuropeanx xastronomersx xwasx xscheduledx xtox xannouncex xonx xWednesdayx xthatx xitx xhadx xfoundx xax xplanetx xthex xsamex xmassx xasx xEarth'sx xinx xAlphax xCentauri,x xax xtriplex xstarx xsystemx xthatx xisx xthex xSun'sx xclosestx xneighbor,x xonlyx x4.4x xlight-yearsx xaway.x xThex xplanetx xisx xthex xlightestx xonex xeverx xfoundx xorbitingx xanotherx xstarx xand--inx xthex xwordsx xofx xitsx xdiscoverer,x xXavierx xDumusque,x xax xgraduatex xstudentx xatx xthex xGenevax xObservatory--"itx xwillx xsurelyx xbex xthex xclosestx xonex xever."x

Condition 5:

xAxxteamxxofxxscientistsxxlaboriouslyxxreviewedxxdecadesxxofxxresearchxxcomparingx xorganicxxfruitsxxandxxvegetablesxxwithxxthosexxgrownxxthexxusualxxway.xxTheyxxfoundx xthat,xxasxxmanyxxhadxxsuspected,xxthexxorganicxxproduce,xxfarmedxxwithoutxxsyntheticx xfertilizersxxorxxpesticides,xxwasxxmorexxnutritious,xxwithxxmorexxvitaminxxC,xxonx xaverage,xxandxxmanyxxmorexxofxxthexxplant-defensexxmoleculesxxthatxxinxxpeoplex xhelpxxshieldxxagainstxxcancerxxandxxheartxxdisease.xxThatxxisxxprobablyxxnotxxthex xstudyxxyouxxheardxxabout.xxThexxfindings,xxbyxxscientistsxxatxxNewcastlexxUniversityx xinxxEngland,xxappearedxxinxxAprilxx2011xxandxxbarelyxxmadexxaxxripplexxinxxthex xnewsxxmediaxxorxxinxxthexxpublicxxconsciousness.x

Condition 6:

ßScientistsßdevelopedßaßprotocolßforßdeterminingßwhichßspeciesßshouldßbeßrescuedßfirst.ß ßAtßthisßpoint,ßonlyß42%ßofßtheßworld'sßamphibiansßhaveßbeenßassessed.ßButßzoosßandß ßaquariumsßhaveßtakenßnoteßandßareßfollowingßtheßprotocol'sßrecommendations.ßSoßfar,ß ßonlyßaboutß10%ßofßtheßamphibianßspeciesßrequiringßimmediateßrescueßhaveßbeenßgivenß ßhomes.ßYes,ßheßsaid,ßthereßareßendlessßmoralßandßethicalßdebates.ßForßexample,ßshouldß ßpriorityßbeßgivenßtoßanimalsßthatßcannotßsurviveßoutsideßzoosßorßtoßthoseßinßneedßofß ßtemporaryßshelterßtoßrestockßtheirßnumbers?ßWhenßthoseßdecisionsßareßmade,ßtheß ßconsequencesßcanßfeelßbrutal.ß

Condition 7:

øTheøNationaløOceanicøandøAtmosphericøAdministrationøacknowledgedøthatøitøhadø øprovidedøtwentyøinstrument-ladenøbuoysøtoøaørecent,øveryøcriticizedøprojectøcarriedøoutø øbyøRussøGeorge.øTheøbuoysødriftøinøtheøoceanøforøaøyearørørmoreøandømeasureøwaterø øtemperature,øsalinityøandøotherøcharacteristics.øSuchøbuoysøareøoftenøsentøoutøonøwhatø øtheøagencyøcallsø"vesselsøofføopportunity,"øandøtheødataøtheyøprovide,øuploadedøtoø øsatellites,øisøpubliclyøavailable.øButøaøspokesmanøsaidøtheøagencyøhadøbeenø"misled"øbyø øGeorgeøandøhisøgroup,øwhichø"didønotødiscloseøthatøitøwasøgoingøtoødischargeømaterialø øintoøtheøocean."ø

Condition 8:

7The7so-called7habitable7zone7of7the7star7Alpha7Centauri7B,7where7temperatures7would7 7be7moderate7enough7for7water7and7creatures7like7us,7is7about7657million7miles7from7 7the7star,7where7a7year7would7take72007days7or7so,7about7the7same7as7the7orbit7of7 7Venus7in7our7own7system.7Mr.7Dumusque7and7his7colleagues7found7a7planet7orbiting7 7Alpha7Centauri7B,7albeit7only747million7miles7away,7by7the7wobble7method.7They7used7 7a7specially7built7spectrograph7called7HARPS7on7a71407inch7diameter7telescope7at7the7 7European7Southern7Observatory7in7La7Silla,7Chile7to7track7the7host7star7as7it7is7tugged7 7to7and7fro7by7the7planet's7gravity.7

Condition 9:

xThe xlemurs xat xthis xzoo xare xbeing xsaved xin xpart xbecause xof xa xwell-financed xprogram xto xrescue xrare xfauna xof xthe xisland xnation xof xMadagascar. xBy xcontrast, xzoos xhave xstarted xgetting xrid xof xlion-tailed xmacaques xin xthe x1990s, xbecause xthey xcan xcarry xa xform xof xherpes xdeadly xto xpeople. xWith xonly xan xaging xpopulation xleft xin xcaptivity xin xthe xUnited xStates, xa xspecies xadvisory xgroup xto xNorth xAmerican xzoos xis xexpected xto xput xthe xanimals xon xa xphaseout xlist xsoon. xIf xthere xare xcriticisms, xthey xare xthat xzoos xare xnot xtransforming xtheir xmission xquickly xenough xfrom xentertainment xto xconservation. x"We xas xa xsociety xhave xto xdecide xif xit xis xgoing xto xbe xethically xand xmorally xappropriate xto xsimply xdisplay xanimals xfor xentertainment xpurposes," xsaid xDr. xSteven xL. xMonfort.

Condition 10:

Ax giantx panda'sx distressx callx sentx keepersx atx thex Nationalx Zoox rushingx tox thex aidx ofx herx tiny,x lifelessx cubx onx Sunday,x andx thex elationx overx thex cub'sx birthx justx ax weekx earlierx turnedx tox despairx overx itsx death.x Zoox officialsx didx notx knowx whatx killedx thex cub,x whichx hadx appearedx tox bex healthy,x butx ax necropsyx wasx performedx onx Sundayx afternoon,x saidx thex zoo'sx chiefx veterinarian,x Dr.x Suzanx Murray.x Zookeepersx realizedx somethingx wasx wrongx onx Sundayx morningx whenx Meix Xiang,x thex cub'sx mother,x issuedx ax distressedx "honking"x noise,x officialsx said.x Itx tookx anx hourx tox retrievex thex cub,x andx thex workersx foundx itx unresponsive.x