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An eight experiment sequence to determine reading equality

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Abstract

An eight experiment sequence was conducted to compare the speed and retention resulting from reading material. The text was justified in each of four different ways: ragged-right (unjustified); fill justified; equal-fill justified; and micro-fill justified. Retention was measured by recall and by recognition tests. For reading time, only one significant difference was found among the eight experiments. For retention, no statistically significant differences were found.

Although our results are in direct contrast to those of other researchers, the consistency of our results make suspect any claim for reading time (or retention) superiority of ragged-right text. These eight experiments demonstrate that all forms of justification read equally well (discounting that micro-fill justification did have an edge in one of the five experiments in which it competed).

Keywords: Reading; Retention; Justification; Justified text; Experimentation

1. Introduction

With the advent of easy access to word processors, computer users now have a whole array of options at their disposal for dressing up and professionalizing the look of their text. One of the most powerful of these options is RIGHT JUSTIFY. With the press of a few keys or buttons, an entire document can be given a smooth crisp right edge. There is a feeling that the improvement in document appearance is more than cosmetic in nature; that is, the effect is more than just removal of the ragged right document edge.

However, a study, by Trollip and Sales [14], seriously questioned the efficacy of justification based on their findings of significantly slower reading speed for fill justified material over ragged-right (unjustified) material. A consequence of their paper may be a reluctance, on the part of some writers, to use justification. For example, many journal instructions to authors request a ragged right margin.

At this point, it is appropriate to present a description of the four varieties of justification.

1. With *ragged-right* (unjustified text) no effort is made to line up the right edge of the text lines. Spacing between letters, punctuation, and words is uniform; every letter and punctuation mark is printed with the same width, which is the same as the inter-word width.

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2. With *fill justification*, the computer sets up a line in the same way as the ragged-right case, but the computer counts the number of extra spaces needed to make the end of that line reach to the predetermined user-defined margin. Using an internal algorithm, the computer then inserts this counted number of additional spaces between the words. Thus, on one line, the space between some words will be larger than between others, and space between words on different lines will also tend to be different (by one or more spaces).
3. *Equal-fill justification* is an improvement over fill justification, in that the extra space on a line is divided into the same number of equal width pieces as there are inter-word spaces. Thus, on any line, all words are separated by equal amounts of space, but, as a consequence of the inter-word spacing, width on adjacent lines is often slightly different.
4. With *micro-fill justification*, the insertion process is further refined by dividing the extra space on a line into a number of slivers equal to the number of characters (both letters and punctuation) on the line minus 1. These equal width slices are then inserted after each character. Like a rubber band, every area of the line is stretched proportionately.

In both of their experiments, Trollip and Sales tested ragged-right versus fill justification and found significantly slower reading speeds (but not poorer retention) for the latter. Drawing on the reading literature, they offered three potential explanations for their finding.

First, referencing Morrison and Rayner [8], they suggest that if the number of characters in a fixation (eye stop) remains a constant and assuming that spaces constitute characters, then with more space between words there will be more saccades (eye jumps) needed to read across a fill justified line.

However, the literature shows that saccadic movement length is variable, the eyes fixating on each successive content word [7, 11, 16]. Additionally, it has been demonstrated that readers do not generally fixate (stop) on the blank areas of a line [1, 2]. Thus, the number of content words and not theoretical fixation width is the relevant factor in determining the number of saccades used to move across a line.

Trollip and Sales' second explanation (for slower reading in the fill justified condition) is that the eyes-mind system has to adjust continually to where the next word starts when there is variable space between words; this requires more time versus the uniform spacing of the ragged-right condition.

However, the literature shows that (1) regardless of inter-word space considerations, the mind must make a decision as to the position of the next word at each fixation [5, 6, 10, 13], (2) but the position of the center of the next word, not the intervening space, is the determinate of the saccadic jump [9, 12, 16] and (3) the processing of this decision occurs simultaneous with the meaning analysis of the currently fixated word, from information provided by the right parafovial (peripheral vision) region of the eyes.

The third explanation offered by Trollip and Sales is that reading flow is disrupted by the larger inter-word gaps that are mistaken by the reader for sentence endings.

However, Rayner has shown that readers do not fixate on the region between sentences. This explanation is also unlikely to be true, because inter-word gaps do not contain the required end of sentence (a period followed by a capital letter). Although Trollip and Sales might suggest that the period is too small to be of much consequence, Zola has shown that even very minor misspellings in expected words (e.g. 'botanical garbens' in a paragraph on tourism) are noticed by readers. Also, as noted above, plans for the width of the next saccade jump are formatted in parallel with meaning analysis at each fixation. Since the parafovial information used for the next saccade calculation is not very fine grained, the period–space–capital letter pattern is the appropriate candidate for end of sentence marker, rather than width of space.

Additionally, it does not seem possible that the entire book publishing industry could be missing the boat. (Books are always right justified.) And it is our experience that it is more tedious to read unjustified newspaper width columns than those that are justified. This seems to be because we are more comfortable knowing, in advance, where each line ends. With respect to this, Just and Carpenter suggest that the eye uses the right margin as the cue for the return sweep. In this case, a ragged right margin should cause margin decisions to be more difficult and so produce slower reading. Thus, even if the arguments of Trollip and Sales should have some partial validity, the knowledge of where each line ends should provide adequate compensation.

In light of the above discussion, we decided to examine equal-fill justification and micro-fill justification versus ragged-right and to include in our studies a fill justification condition as well. Hyphenization was not a part of any of the justification procedures and was not used in creating any of the texts. Our dependent variables were reading time and retention.

The three studies consisted of eight experiments across a wide range of texts using 166 subjects. It should be noted that one refinement we included in our report is a Gunning Fog Index measurement [4] of the reading complexity of each of our text materials. Of the over 50 readability indices available, we chose the Gunning because it is most frequently cited and most widely used [3], undoubtedly because it is scored in terms of years of schooling necessary to read the target material. Its accuracy has been assessed to be within one grade level.

2. Method

2.1. General

Three studies were conducted. The first one consisted of two experiments; the second and third consisted of three experiments each. Thus, there were eight experiments. Each was of the 'between group' type, that is, in any experiment, a subject read only one type of justified material. All subjects were tested individually. Reading was timed by stopwatch. The retention test (multiple choice or fill in the blank) was not timed. Retention scores for each experiment were obtained by awarding one point for each correct answer and summing to find a total.

Text documents were printed double spaced on 8 1/2×11 white paper, with approximately a one inch margin on all edges. All texts were produced in Pica type with a point size of 10. The Gunning Fog Indexes for our eight experiment texts ranged from a grade level 8.9 to a grade level 17.3. By way of comparison, the Fog Index for the text used by Trollip and Sales was grade level 13.1. The characteristics of the eight texts (one for each experiment) are presented in Table 1.

In each of the studies, each subject read the assigned text and then, with the text removed, completed a 10 question retention test pertaining to the material. This was repeated for a second text. Study 2 (experiments 3, 4, and 5) and Study 3 (experiments 6, 7, and 8) were identical in form to Study 1, except that each subject read three texts (instead of two), completing a multiple choice retention test after each reading.

2.1.1. Study 1 (experiments 1 and 2)

2.1.1.1. Subjects (experiments 1 and 2)

Sixty subjects, juniors, seniors, and graduate students at a US urban technical university were randomly assigned to one of three groups, ragged-right, fill justification or equal-fill justification, with the restriction that the number of females in each group be approximately equal; 17 percent were female. Mean age of all 60 subjects was 25.8 years with a standard deviation of 4.6 years. The groups were tested for equality on sex, type of employment, years of education, years of employment and age. A chi–square on nominal variables sex, and type of employment, a Kruskal–Wallis on ordinal variable years of

Table 1
Text characteristics for the eight experiments

Exp	Topic	Total pages	Total lines	Total words	Lines per full page	Average words per full page	Average words per full line	Gunning index (Grade level)
1	Petroleum deposits	4	89	867	25	249	10.7	17.3
2	Animal camouflage	3	66	598	26	237	10.9	16.3
3	Usefulness of trees	6	170	1610	26	248	10.2	8.9
4	Using the brain	8	204	2008	26	251	10.2	13.7
5	Conodant fossils	8	213	1978	26	240	10.5	15.5
6	Ice age legacy	4	125	1308	28	279	10.3	9.3
7	Search for pepper	6	162	1833	28	303	12.0	12.0
8	Dogs for the deaf	5	163	1726	27	291	11.2	13.1

education and an ANOVA on years of employment and age all found no difference among the three groups (all p's>0.2).

2.1.1.2. Procedure (experiments 1 and 2)

At the start of the experiments each subject was told he/she would be given two papers to read and that after each reading he/she would be tested on the material just read. The subject was also told that the reading would be timed.

Experiment 1. Depending on condition (ragged-right, fill justification or equal-fill justification) the subject was given the appropriate justified text (concerning animal camouflage) and asked to read it at his/her normal rate of speed for good retention. When the reading was finished, the subject was given a 10 question recognition (multiple choice, four alternative) quiz and asked to circle the correct answers (one point being awarded for each correct answer). Samples of the text and of the related questions are presented in Fig. 1.

Cryptic coloring is by far the commonest use of color in the struggle for existence. It is employed for the purpose of attack (aggressive resemblance or anticryptic coloring) as well as of defense (protective resemblance or procryptic coloring). The fact that the same method, concealment, may be used both for attack and defense has been well explained by T. Belt who suggests as an illustration the rapidity of movement which is made use of by both pursuer and pursued .....

Cryptic coloring, whether used for defense or attack, may be either general or special. In general resemblance the animal, in consequence of its coloring, produces the same effect as its environment but the conditions do not require any special adaption of shape and outline. General resemblance is especially common among the animals inhabiting some uniformly colored expanse of the earth's surface, such as an ocean or a desert. In the former, the animals of all shapes are frequently protected by their transparent blue color; on the later, equally diverse forms are defended by their sandy appearance.

8) The fact that concealment may be used for attack as well as for defense has been explained by:
   1. T. Belt
   2. G. L. L. Buffon
   3. J. B. P. Lamarck
   4. E. B. Poulton

9) According to the text, general resemblance is especially common among animals inhabiting:
   1. uniformly colored expanses of the earth's surface
   2. hilly and green territories
   3. areas comprised of differently colored patches
   4. dry lands

Fig. 1. A sample of the text and questions used in Experiment 1.

Texts (for this and Experiment 2) were created using Microsoft Word Version 4.0. Applicable settings were:

Ragged-right – Format Paragraph Alignment=Left;
Fill Justification – Format Paragraph Alignment= Justified, Printer Options Draft=Yes;
Equal-fill Justification – Format Paragraph Alignment=Justified, Printer Options Draft=No.

Texts were printed using an Epson RX-80 printer.

Experiment 2. The subject was given the second text concerning petroleum and its 10 question recall test. Samples of the text and questions are presented in Fig. 2.

Type of justification tested was rotated for the three groups, so that the Experiment 1, namely Ragged-right group became Experiment 2, namely Fill justification group, etc.

2.1.2. Study 2 (experiments 3, 4, and 5)

2.1.2.1. Subjects (experiments 3, 4, and 5)

Sixty subjects, as described before, were randomly assigned to one of the three groups with females still equally distributed across them. Thirty-six males and 24 females participated. The mean age was 24.1 years with a standard deviation of 2.5 years. The groups were compared for equality on sex, occupation, types of material read (magazines, newspapers, books, technical papers), years of education, reading frequency (daily, weekly, monthly, rarely) and age. A chi–square test on nominal sex, occupation, and types of material read, a Kruskal–Wallis on ordinal years of education and reading frequency and an ANOVA on ratio variable age all yielded no difference (all p's>0.1).

Four general conditions seem to be necessary for the accumulation of recoverable quantities of petroleum: (1) strata containing organic matter to provide sources for petroleum formation, since oil is probably formed by the decomposition of marine organizations; (2) rocks with openings to serve as porous reservoirs for organic matter which has been buried; (3) impermeable layers of rocks on top of the reservoir rocks to prevent the escape of crude oil; and (4) suitable elevated structural features to allow the oil, water and gas to separate. Anticlines, faults, unconformities, domes, salt or sulphur plugs, buried coral reefs and additional stratigraphic traps are structural features which may include oil if the first three prerequisites are also met.

Petroleum is a mixture of hydrocarbons formed as tiny marine animals are covered by mud, silt and sands. The sands and mud which were deposited on the shores of ancient seas, then were subjected to the pressures of other deposits above them and turned into sandstone and shale. The marine organic matter held in the sand and mud slowly turned into crude oil.

5. Petroleum is created by decomposition of _____ matter.

6. Sandstone is created by _____.

Fig. 2. A sample of the text and questions used in Experiment 2.

2.1.2.2. Procedure (experiments 3, 4, and 5)

Experiments 3, 4, and 5. The procedure was the same as for Study 1. All three recognition tests consisted of 15 multiple choice four alternative questions. Samples of the texts and the associated questions are presented in Figs. 3–5.

The three text documents were created using Word Perfect Version 5.0. Word Perfect Printer Settings were as follows:

Ragged-right – Justification=Off;
Fill Justification – Word Spacing=Optimal, Letter Spacing=Optimal, Compressed=0%, Expanded=Unlimited;
Micro-fill Justification – Word Spacing=Optimal, Letter Spacing=Optimal, Compressed=100%, Expanded=100%.

The texts were printed using a Laserjet II printer.

2.1.3. Study 3 (experiments 6, 7, and 8)

2.1.3.1. Subjects (experiments 6, 7, and 8)

Forty college educated adult employees of a large communications service company were randomly assigned to two groups, ragged-right and micro-fill justification, subject to the condition that each had six females and 14 males. The average age of the 40 subjects was 34.1 years. The two groups were compared for equality on years of education and age. A Mann–Whitney test on ordinal years of education and a *t*-test on ratio variable age both yielded no difference (both p's>0.2).

2.1.3.2. Procedure (experiments 6, 7, and 8)

Experiments 6, 7, and 8. The procedure was the same as for the other studies. Samples of the texts and the associated questions are presented in Figs. 6–8.

Trees are so common and quiet that we pay them little mind. What, for instance, should we answer when asked to name the biggest living thing Earth has ever seen? Dinosaurs? Blue whales? No, the largest living sequoias in northern California weigh more than six blue whales. The tallest redwoods and Australian eucalyptus trees tower more than 300 feet high, three times the length of the greatest dinosaur.

You think, at 150 or more years, giant tortoises can live a long time? Some bristlecone pine trees in the American West are more than 4000 years old, seedlings at the time the Egyptians were building the Pyramids.

2. The Australian eucalyptus tree is:
   a. about the size of a dinosaur
   b. three times the length of the greatest dinosaur
   c. about the size of a blue whale
   d. about twice the size of a blue whale

3. Some bristlecone pine trees are more than ___ years old.
   a. 2000
   b. 3000
   c. 4000
   d. 5000

Fig. 3. A sample of the text and questions used in Experiment 3.

What exactly happens to the adult nervous system when we want to make a change or break a habit? "Our understanding of the process is very sketchy," Squires says. New learning must entail structural change in the neurons and synapses. But instead of a whole new pathway being formed, he says, the existing pathways may be reshaped. To form a new habit, you might alter the old pathway, instead of laying down an entirely new one. Rather than disappearing, the old pathway would simply weaken.....

Whether you take advantage of the fact or not, the adult brain remains extremely flexible into old age. Although some of our abilities decline, we compensate. We make lists to shore up a shaky memory. But neurobiologists have shown that we can continue to lay down new synaptic networks well into our 80s or 90s.

2 To form a new habit:
a. new pathways must always be formed
b. old pathways must be destroyed
c. existing pathways may be reshaped
d. new neurons must be created

10 According to the text, older people an shore up shaky memory by:
a. using mental tricks
b. making lists
c. asking a friend to help them remember
d. repeating the thing to be remembered several times

Fig. 4. A sample of the text and questions used in Experiment 4.

The three text documents were created using the Multimate Advantage II word processor and printed using the following settings:

Ragged-right – Normal, with no proportional spacing
Micro-fill Justification – Micro justification with proportional spacing

The texts were printed using a Laserjet II.

It should be noted that the article used in Experiment 8 was a reduced version (6.5 instead of 14.5 pages) of the Trollip and Sales test article [15].

3. Results

All numerical results are shown in Table 2.

Results of statistical testing are shown in Table 3. Only one significant difference was found for reading time: in Experiment 5, in favor of the micro-fill justification condition; the other two conditions (fill and micro-fill) were statistically equivalent. However, it is to be noted that the micro-fill justification condition was not found significantly better than other conditions in five other experiments (3, 4, 6, 7, and 8). No other significant difference was found in any experiment for either reading time or for retention testing. There was not even a reading time ordering in favor of the ragged-right condition. In fact, in two of the five comparisons with fill justification, in one of the two comparisons with equal-fill justification, and in four of the six comparisons with micro-fill justification, the ragged-right condition produced a slower reading time.

"Conodont elements progressively change color from an unaltered light amber - their natural color - through completely black and then to a translucent white," explains Clark. "This has been directly correlated with the formation temperature of the rock in which the conodonts are preserved.

Petroleum cannot survive in rocks heated above certain temperatures. Oil is 'cooked' out of the rock after about 140 centigrade - it may be driven out into the surrounding porous sediments or break down into other components. Natural gas survives a little bit longer. So if an oil geologist finds a rock with a conodont with a CIA of five - which means the rock has been heated beyond 140 centigrade - then he knows that the rock hidden underground cannot contain petroleum or natural gas."

3. The natural color of conodont elements is:
   a. amber
   b. black
   c. translucent white
   d. light green

4. Oil is 'cooked' out of the rock after about ___ centigrade.
   a. 94
   b. 104
   c. 140
   d. 240

Fig. 5. A sample of the text and questions used in Experiment 5.

Table 2
Average reading time and average retention scores for eight experiments

	Average reading time (s)				Average retention score						Gunning index (Grade level)
Exp	R-Rt [a]	Fill [b]	E-fill [c]	Micro [d]	R-Rt [a]	Fill [b]	E-fill [c]	Micro [d]	Type	Max-poss.	
1	293	313	338		5.1	5.9	4.3		recog	10	17.3
2	281	243	242		5.3	6.6	5.8		recall	10	16.3
3	560	552		497	10.7	9.4		11.0	recog	15	8.9
4	687	692		629	10.3	9.9		10.5	recog	15	13.7
5	750	764		639	10.4	8.8		9.7	recog	15	15.5
6	563			568	7.2			7.2	recog	10	9.3
7	580			569	7.2			7.4	recog	10	12.0
8	658			656	9.2			9.5	recog	10	13.1

[a] Ragged right.
[b] Fill justification.
[c] Equal-fill justification.
[d] Micro-fill justification.

The U.S. and Canadian farm belt is especially indebted to the glacial face lift. Geologists believe that most of its productive soil - up to 150 feet thick in Iowa - was scooped out of lowlands now occupied by the Great Lakes, Later, meltwater streams deposited thick layers of silt and sand beyond the ice front. Eroded and borne by the wind this dustlike mantle eventually settled in drifts as far south as Louisiana.

Some of our most fertile agricultural areas are a gift from long-vanished Lake Agassiz, which inundated more than 100,000 square miles in North and South Dakota, Minnesota, Ontario, Manitoba and Saskatchewan. Lake Agassiz was created by a massive ice dam. Meltwaters feeding the lake deposited huge amounts of silt and clay. When the dam melted, the lake drained northward into Hudson Bay.

5. Geologists believe that most of the productive soil in the farm belt of the U.S. and Canada was scooped out of lowlands now occupied by what?
   a. The Rocky Mountains c. The Great Lakes
   b. The Bering Glacier d. The Mississippi River

10. As a result of the glaciers, how many feet of productive soil were deposited in Iowa?
   a. 50 feet c. 250 feet
   b. 150 feet d. 350 feet

Fig. 6. A sample of the text and questions used in Experiment 6.

4. Conclusions

It can be concluded that fill justified text, equal-fill justified text and micro-fill justified text are all read at least at the same speed as ragged-right text (and with equal retention). This is in contrast to the results obtained by Trollip and Sales. Thus, justification of any type may be used as and when desired without fear of compromising reading speed or retention.

5. Discussion

We are at a loss to explain the difference in results between our work and that of Trollip and Sales. Their

Table 3
Statistical tests performed and statistical results for the eight experiments

Exp	Statistical tests performed	Result for task time	Duncan range test	Result for retention scores
1	ANOVA	$p>0.05$	na	$p>0.05$
2	ANOVA	$p>0.05$	na	$p>0.05$
3	ANOVA	$p>0.2$	na	$p>0.1$
4	ANOVA	$p>0.2$	na	$p>0.1$
5	ANOVA	$p<0.05$	MJ<RR=FJ	$p>0.1$
6	*t*-test	$p>0.2$	na	$p>0.2$
7	*t*-test	$p>0.2$	na	$p>0.2$
8	*t*-test	$p>0.2$	na	$p>0.2$

RR=ragged right; FJ=Fill justification; MJ=Micro-fill justification; na=not applicable.

The duties levied on that pepper in the customhouses of Alexandria was one of the mainstays of the Imperial budget. And all that gold flowing to Muziris and the other ports of India deepened the deficit in the balance of payments which, according to one school of modern historians, led to the financial crisis that helped destroy the Roman Empire.

After Rome fell, pepper became much rarer and more expensive in the Western world. The Dark Ages of Europe were the Pepperless Ages as well, in which many people found little better to flavor their food than onion, garlic and a few other herbs.

The flow of pepper to Europe increased again as a result of an economic and commercial boom that began at the end of the 11th century. When the beefy barons of the North, sailing to the Holy Land on the Crusades, found pepper in the Near East - one of the most notable features of the boom - they went crazy over it. The eating habits of a continent were changed almost overnight.

4. One of the main cities through which pepper flowed into the Roman Empire was:
   a. Cairo c. Alexandria
   b. Babylon d. Athens

6. At the end of the 11th century, pepper was reintroduced into Europe because of:
   a. Arab explorers c. Italian sea merchants
   b. Portuguese explorers d. the Crusades

Fig. 7. A sample of the text and questions used in Experiment 7.

subjects were similar to ours in years of schooling: upper level undergraduate and graduate students. Sample sizes for their Experiment 1 (21 and 25) were reasonable (20 or more) and approximately the same as ours. Their Experiment 2 sample sizes (46 and 47) were even larger. They used text printed in Pica 10, double spaced on 8 1/2×11 white paper, as did we. Our reading time averages ranged from a low of 4.2 min to a high of 12.4 min (depending on experiment). Their reading time averages ranged from 13.6 to 16.5 min. The differences do not appear large enough to be a factor. Larger times undoubtedly mean their text was longer than any of ours. But this feature would seem unlikely for explaining the difference; in a number of our experiments (2 out of 5), the ragged-right condition took longer to read, on average, than did the fill justified condition and presumably longer text would not cause a reversal of this relationship (ragged takes longer).

The only question we can pose concerning the Trollip and Sales procedure is that they tested their subjects a group at a time, requiring each subject to record his/her own start and stop times, while we tested subjects individually, with time being kept and recorded by the experimenter.

The weight of the consistent results found in our eight experiments make suspect any claim for the reading speed (or retention) superiority of ragged-

It is estimated that there are 3.5 to 4 million people in the United States who are profoundly hearing impaired and another 14 million who suffer some degree of hearing loss, Of course, a dog does not fit into every lifestyle. But for those who are interested, these dogs can add a degree of independence and security to their lives.

Currently, there are about 27 signal dog programs in the United States. They usually recruit their trainees from humane societies and shelters, helping unwanted animals that otherwise might never find homes. The requirements for a signal dog (also known as hearing ear dog or hearing dog) are fairly simple. The dog must be young, friendly, alert and willing to learn. Older dogs can be trained, but ideally, candidates should have many years of service ahead of them.

3. From where are dogs usually obtained to be trained as signal dogs?
   a. Humane societies and animal shelters
   b. Special breeding programs
   c. Pets of the hearing impaired
   d. From 4-H clubs

10. How many signal dog programs are there in the United States at the current time?
   a. 19 c. 39
   b. 27 d. 47

Fig. 8. A sample of the text and questions used in Experiment 8.

right text; it would appear that all forms of justification (including ragged-right) read equally well.

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