# Visual versus phonological route in the processing of homophones in printed sentences

**by Patricia Karsten**

## Abstract

To assess the relative importance of the visual versus phonological routes in 'reading for meaning' for readers of English, a sentence-verification task was used, comparing performance for high versus low frequency words in original and homophonic sentences in a within-participants design. Data from 140 participants of mixed age, gender and nationality showed that original sentences were processed generally faster than homophonic sentences, but the performance advantage was large only for high frequency, not for low frequency words. The observed interaction between sentence spelling and word frequency suggests that the visual route is very important for high frequency words, but less so for low frequency words.

## Introduction

Psychological research into reading aims at understanding the processing of written words. Reading can be silent or aloud, and may even bypass understanding, for example reading a text in a foreign language without possessing adequate vocabulary. Therefore, when researching 'reading for meaning', word comprehension is typically assured by administering lexical decision tasks, for example determining whether a word is a word, or if the word belongs to a category (Gaskell 2005).

According to the dual route account, there are two main processing routes for written words: The visual route, where recognition of a written pattern enables direct access to the meaning of the word, and the phonological route, where the written pattern is first mapped to a phonological representation via assembled (rule-based) or addressed (pattern recognition) phonology, in order to access its meaning. Both visual and phonological routes can be used, and whichever is faster, determines response times (Coltheart et al. 1977).

Rubenstein et al. (1971, as cited in Naish, 2008) posited that the phonological route was always used first, with subsequent control by a spell-checking mechanism which ruled out wrong alternatives. In opposition to this, Coltheart et al. (ibid.) argued that the visual route enabled direct access to meaning, with the possibility to completely bypass the phonological route for skilled readers. But Van Orden (1987, as cited in Naish, 2008) concluded from homophone categorization experiments that the phonological route is always involved, even when this leads to slower processing.

Homophones are words that have the same pronunciation, but different orthography and different meanings, for example 'you' and 'ewe', and are widely used in research into reading. Besides homophony, word frequency also seems to play a role for the speed with which written words are processed. In lexical decision tasks, high frequency words are typically processed faster than low frequency words. This can be explained with the dual route account: High frequency words make use of a strengthened visual route with fast direct access, but for low frequency words, the visual route is weaker and so the phonological route, which needs an additional recoding step to access meaning, comes into play, increasing overall response times (Naish, 2008).

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The current study aimed to further assess the relative importance of the two processing routes in the context of sentence comprehension. Word frequency and sentence spelling were used as independent variables. Sentences consisted of either high-frequency or low-frequency members of homophone word pairs, for example:

Original spelling, high frequency words:
*Both feet can be on the floor and ceiling at the same time*
Homophonic spelling, low frequency words:
*Both feat can be on the flaw and sealing at the same thyme*

The original sentences were understandable via both routes, whereas homophonic sentences could be understood via the phonological route, providing positive evidence for its use as demanded by Coltheart et al. (ibid). The time needed to understand 'normal' versus 'homophonic' sentences, consisting of high or low frequency words, was the dependent variable. If the visual route was principally employed, the meaning of a normal sentences would be accessed immediately, but understanding of the homophonic sentence would require an additional processing step of phonological recoding, leading to the first hypothesis:

> Homophonic sentences will take longer to understand than correctly spelled sentences.

In this context, it was interesting to assess whether sentence processing speed always followed the above described tendency of faster processing for high frequency words, as implied in the second hypothesis:

> Sentences with low frequency words will take longer to understand than sentences with high frequency words.

It was expected that the effect of high versus low word frequency might be different for original compared to homophonic sentences. In original sentences, high frequency words should be processed faster than low frequency words, due to the efficient visual route. In homophonic sentences, the strong visual route for high frequency words might make it difficult to access the required alternative meaning via the phonological route, whereas for low frequency words, the visual route would be weaker, allowing easier access to the correct meaning via the phonological route. So the change from high to low frequency words was expected to cause a slower response in original sentences, but a faster response in the homophonic sentences, leading to the third hypothesis:

> There will be an interaction between spelling and word frequency. The change from high to low frequency words will delay responses for original sentences, but speed up responses for homophonic sentences.

## Method

### Design

The experiment employed a within-participants design with four conditions, assessing the effect of spelling (original or homophonic) and word frequency (high or low) on sentence processing speed, measured as mean reaction time in a sentence verification task.

Participants

Participants were OU psychology undergraduate students of mixed age, gender and nationality. They were English native speakers or had adequate knowledge of English to follow a level 3 psychology course. Participants were supposed to remain naïve to the research hypothesis prior to the experiment (Naish, 2008).

Materials

The stimuli consisted of two matched and counterbalanced sets of 40 sentences each. Each list contained 20 original and 20 homophonic sentences, further halved into high versus low frequency words. One half of each sentence type was true or reasonable, the other half was false (see appendix I for list of stimuli). The stimuli were presented with E-Prime.

Procedure

Participants were assigned to one of the stimulus sets according to their birthday and instructed how to self-administer the test using E-Prime. Participants were presented with one sentence at a time in random order. They had to press the x key for a false and the M key for a true or reasonable statement. For each sentence, response time and accuracy were recorded. A short practice section preceded the experiment, and participants were thanked afterwards (see appendix II for full instructions).

## Results

Data from 140 participants of Open University regions 09 and 11 were analyzed using a 2x2 repeated-measures ANOVA, including error responses, outliers and extreme values. The first factor was sentence spelling, with two levels, original or homophonic. The second factor was word frequency, with two levels, high or low.

Table 1 shows all means. With respect to sentence spelling, participants had faster overall mean reaction times for original sentences (4,952 ms) than for homophonic sentences (7,430 ms). The difference was significant ($F_{1,139} = 258.44$, $p < 0.0005$). Concerning word frequency, participants had faster overall mean reaction times for low (5,843 ms) than for high frequency sentences (6,539 ms). The difference was also significant ($F_{1,139} = 35.921$, $p < 0.0005$).

The interaction between the two factors was also statistically significant ($F_{1,139} = 232.089$, $p < 0.0005$) and is illustrated in figure 1. The high frequency original sentences had faster reaction times (4,223 ms versus 5,682 ms), whereas the high frequency homophonic sentences had slower reaction times (8,855 ms versus 6,006 ms) than their respective low frequency counterparts (see Appendix III for SPSS output).

**Table 1: Participants' mean reaction times in ms**

| | | Factor 2: Word frequency | | |
|---|---|---|---|---|
| | | High frequency | Low frequency | overall |
| Factor 1: Sentence spelling | Original sentences | 4,223 | 5,682 | 4,952 |
| | Homophonic sentences | 8,855 | 6,006 | 7,430 |
| | overall | 6,539 | 5,844 | 6,191 |

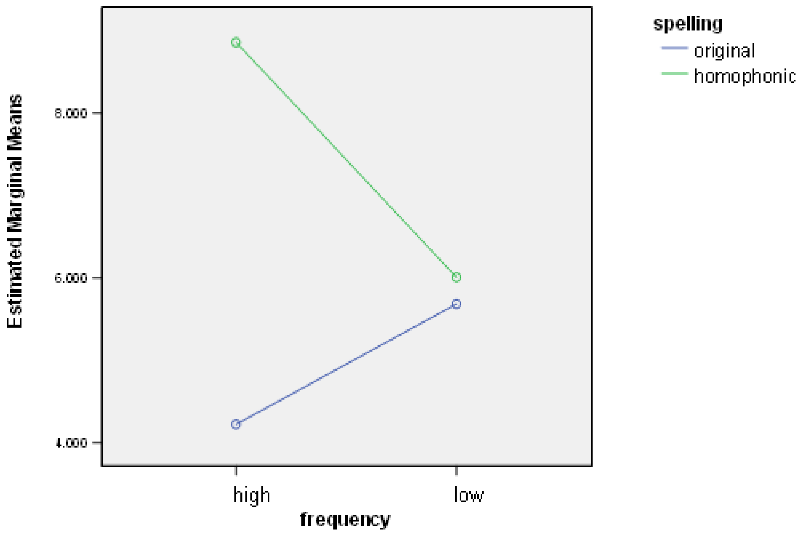



**Figure 1: Interaction between sentence spelling and word frequency**

**Discussion**

The main effect for spelling was faster mean reaction times for original than for homophonic sentences, irrespective of word frequency, supporting the first hypothesis. The main effect for word frequency was faster mean reaction times for low frequency compared to high frequency homophones, which contradicted the second hypothesis. This overall effect was the result of opposite effects of word frequency on processing speed for original versus homophonic sentences, as predicted by the third hypothesis which suggested an interaction between spelling and word frequency. Thus, the results support the third hypothesis, with low frequency replacements causing a delay for original sentences, but causing faster processing in homophone sentences.

These results were generally in line with the dual route account, and showed that both visual and phonological routes could be used to access meaning. The fast processing times for high frequency original sentences supported the idea of a strong and fast visual route which bypassed the phonological route. At the same time, the relatively slow processing times for high frequency homophonic sentences suggested that a strong visual route made it very difficult to access the alternative, correct word meaning via the phonological route.

On the other hand, for low frequency words, there was only a tiny performance advantage for original over homophonic sentences, suggesting that the visual route was less important here. While still enabling faster processing for original sentences, the visual route seemed indeed to have been less disturbing in low frequency homophonic sentences. This lead to the conclusion that word frequency made a difference for the relative importance of visual versus phonological route: The visual route seems to be relatively more important in the processing of high frequency vs. low frequency words.

When interpreting the results, it should be taken into account that individual differences in experienced word frequency may exist (Naish, 2008). In the current experiment, these were controlled by a within-participants design, but they have an interesting implication. Skilled readers should have generally higher word frequency levels than less able readers. The experimental findings imply that skilled readers make heavier use of the visual route, while less skilled readers with lower word frequency levels would rely more on the phonological route. Skilled readers should therefore show larger performance differences between original and homophonic sentences than less able readers. This hypothesis might be tested in future research.

Using sentences rather than isolated words, as in many other relevant studies, allowed better insight into cognitive processes during reading (Naish, 2008). But the experimental results may still lack ecological validity, because homophonic sentences as they were used here do not occur in normal reading. Slower response times for homophonic sentences may therefore reflect how efficiently human brains adapt to cultural norms incorporated in spelling rules, but the findings do not imply that the phonological route is innately less efficient than the visual route in reading.

## References

Coltheart, M., Davelaar, E., Jonasson, J.T. and Besner, D. (1977) 'Access to the internal lexicon', in Dornic, S. (ed.) *Attention and Performance VI*, Hillsdale, NJ, Lawrence Erlbaum

Gaskell, G. (2005) 'Language processing, in Braisby, N. and Gellatly, A. (eds) *Cognitive Psychology*, The Open University, Milton Keynes, pp. 197-230

Naish, P. (2008) *Project Booklet 2 for DD303 Cognitive Psychology*, The Open University, Milton Keynes

## Appendices

Appendix I: Complete stimulus list

| Sentence | Type | Frequency |
|---|---|---|
| If you encounter a bike on the path it might ring its bell | O | High |
| In February there are more than seven days to a week | O | High |
| At sea, boats without sails can be rowed with an oar | O | Low |
| Storks are bred for their meat in parts of Greece | O | Low |
| The seam of a ruff frays if it is flawed | O | Low |
| Army colonels usually lead naval people to war | O | High |
| In a race a hoarse mite do several lapse of a coarse | H | Low |
| Hairs once eight meet; now they just nor roots | H | High |
| Place are court from the see sure by fishing real | H | High |
| At some time we are all going to die | O | High |
| A cheque can buy an expensive phial of scent | O | Low |
| The some of for plus ate through Einstein into a complete days | H | High |
| As heir to the throne Anne will reign four years from now | O | Low |
| Cats' pause have for clause to catch pray | H | High |
| Thyme is said two weight four know man | H | Low |
| Blew genes are made of woven hoarse hare | H | Low |
| Yew, fir and beech are all types of bean | O | Low |
| Both feet can be on the floor and ceiling at the same time | O | High |
| Every child needs to be taught how to read and write | O | High |
| In Rome the write weigh to hale Caesar was to stair at Hymn! | H | Low |
| The mail dear is also called a dough | H | High |
| Won uses doe to make wholemeal bred | H | Low |
| A sun is always a grater age than his farther | H | Low |
| The expression "Wrings a belle" means you have knot herd it before | H | Low |

| | | |
|---|---|---|
| Macbeth met a which, with hooked knows, in the missed on the more | H | High |
| Arthur’s nights road and sort an earn - the Holy Grail | H | High |
| When you here Pavarotti’s voice it is a week, horse wine | H | High |
| A polar bear has thick hair all over its paws | O | High |
| Henry VIII eight pairs in a vein attempt to lose wait | H | High |
| Wee mown and grown when we have flew - it’s such a pane | H | Low |
| An awl makes a hole in wood, such as beech | O | Low |
| A none used to where course cloth against bear skin | H | High |
| A weak male can't take a four ton weight up stairs | O | Low |
| The garden rose is a blue flower with no scent | O | High |
| On the dance flaw at the bawl Cinderella was a grate cite | H | Low |
| Blair was fined two cents when he blew aloud at President Bush! | O | Low |
| The genes govern whether you weigh too much | O | Low |
| Our days on this Earth may be few | O | High |
| They cell moor ail than whine in France | H | Low |
| Seven take away one comes to more than eight | O | High |
| If ewe encounter a bike on the path it mite wring its belle | H | Low |
| In February there are moor than seven daze two a weak | H | Low |
| At see, boats without sales can be road with an or | H | High |
| Stalks are bread for their meet in parts of grease | H | High |
| The seem of a rough phrase if it is floored | H | High |
| Army kernels usually lead navel people too wore | H | Low |
| In a race a horse might do several laps of a course | O | High |
| Hares once ate meat; now they just gnaw roots | O | Low |
| Plaice are caught from the sea shore by fishing reel | O | Low |
| At sum thyme we ah all going to dye | H | Low |
| A check can by an expensive file of sent | H | High |
| The sum of four plus eight threw Einstein into a complete daze | O | Low |
| As air to the thrown Anne will rain for years from now | H | High |
| Cats' paws have four claws to catch prey | O | Low |
| Time is said to wait for no man | O | High |
| Blue jeans are made of woven horse hair | O | High |
| You, fur and beach are all types of been | H | High |
| Both feat can be on the flaw and sealing at the same thyme | H | Low |
| Every child kneeds two be taut how to reed and rite | H | Low |
| In Rome the right way to hail Caesar was to stare at him! | O | High |
| The male deer is also called a doe | O | Low |
| One uses dough to make wholemeal bread | O | High |
| A son is always a greater age than his father | O | High |
| The expression "Rings a bell" means you have not heard it before | O | High |
| Macbeth met a witch, with hooked nose, in the mist on the moor | O | Low |
| Arthur’s knights rode and sought an urn - the Holy Grail | O | Low |
| When you hear Pavarotti’s voice it is a weak, hoarse whine | O | Low |
| A polar bare has thick hare awl over its pause | H | Low |
| Henry VIII ate pears in a vain attempt to lose weight | O | Low |
| We moan and groan when we have flu - it’s such a pain | O | High |
| An all makes a whole in wood, such as beach | H | High |
| A nun used to wear coarse cloth against bare skin | O | Low |
| A week mail can't take a for ton wait up stares | H | High |
| The garden rows is a blew flour with no cent | H | Low |
| On the dance floor at the ball Cinderella was a great sight | O | High |
| Blair was find to scents when he blue allowed at President Bush! | H | High |
| The jeans govern weather you way to much | H | High |
| Hour daze on this Earth may bee phew | H | Low |
| They sell more ale than wine in France | O | High |

| | | |
|---|---|---|
| Severn take away won comes to moor than ate | H | Low |

Appendix II: experimental instructions employed in E-Prime

| |
|---|
| **Put one finger on the X, one on the M and a thumb or other finger on the space-bar.<br>X is for 'untrue', M for 'may be' or 'true', and the space-bar makes the next display appear, when you are ready.<br><br>You will see a series of printed statements, some with misspellings (e.g. putting 'sum' instead of 'some'). Ignore the spelling, and going on the sound of the words, decide as quickly as possible whether the statement is untrue, or whether it is (or may be) correct. Make sure you have understood the sentence before responding.<br><br>Press space-bar when ready to continue** |

| |
|---|
| **First you will have a short practice, with just a few sentences to judge.<br><br>Remember: type X if they are wrong, or M if they might be true.<br><br>After each response, use the space-bar when you are ready for the next sentence.<br><br>IGNORE THE BAD SPELLING!<br><br>If you are ready now, please type the space-bar …** |

| |
|---|
| **Well done! Now you will do the experiment proper. Press the space bar when you are ready to go on.** |

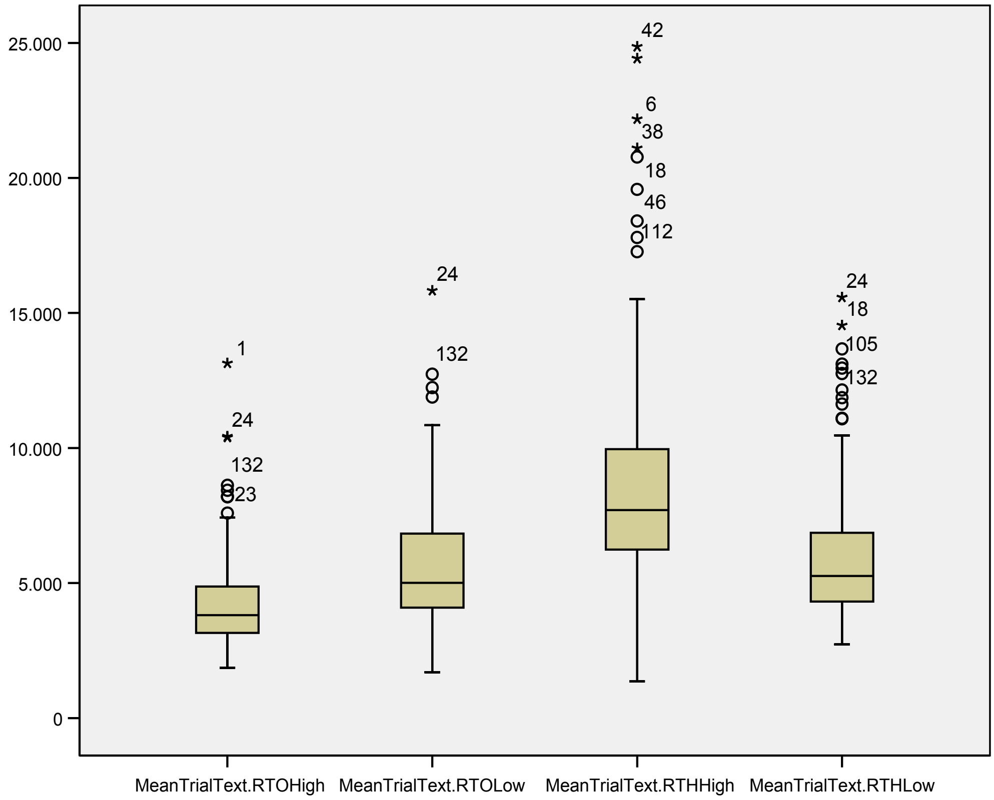
| |
|---|
| **Thank you very much<br><br>Eye no it mite seam hard, but that's awl!** |

Appendix III: full SPSS output

**Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| MeanTrialText.RTHHigh | 140 | 1358 | 24861 | 8855,23 | 4263,207 |
| MeanTrialText.RTHLow | 140 | 2730 | 15579 | 6005,69 | 2597,876 |
| MeanTrialText.RTOHigh | 140 | 1866 | 13138 | 4222,74 | 1764,259 |
| MeanTrialText.RTOLow | 140 | 1700 | 15827 | 5682,19 | 2423,065 |
| Valid N (listwise) | 140 | | | | |

**Simple boxplot with summaries of separate variables**




**Estimated marginal means**

**Within-Subjects Factors**

Measure: Mean_Reaction_Time

| spelling | frequency | Dependent Variable |
|---|---|---|
| 1 | 1 | MeanTrialText.RTOHigh |
| | 2 | MeanTrialText.RTOLow |
| 2 | 1 | MeanTrialText.RTHHigh |
| | 2 | MeanTrialText.RTHLow |

**1. Grand Mean**

Measure: Mean_Reaction_Time

| Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|
| | | Lower Bound | Upper Bound |
| **6191,459** | 215,052 | 5766,263 | 6616,655 |

**2. spelling**

Measure: Mean_Reaction_Time

| spelling | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| 1 | **4952,461** | 170,914 | 4614,533 | 5290,388 |

| | | | | |
|---|---|---|---|---|
| 2 | **7430,457** | 274,159 | 6888,397 | 7972,518 |

**3. frequency**

Measure: Mean_Reaction_Time

| frequency | Mean | Std. Error | 95% Confidence Interval Lower Bound | Upper Bound |
|---|---|---|---|---|
| 1 | **6538,982** | 239,434 | 6065,578 | 7012,386 |
| 2 | **5843,936** | 204,671 | 5439,265 | 6248,607 |

**4. spelling * frequency**

Measure: Mean_Reaction_Time

| spelling | frequency | Mean | Std. Error | 95% Confidence Interval Lower Bound | Upper Bound |
|---|---|---|---|---|---|
| 1 | 1 | **4222,736** | 149,107 | 3927,924 | 4517,547 |
| | 2 | **5682,186** | 204,786 | 5277,287 | 6087,085 |
| 2 | 1 | **8855,229** | 360,307 | 8142,838 | 9567,619 |
| | 2 | **6005,686** | 219,561 | 5571,575 | 6439,796 |

**Tests of Within-Subjects Effects**

Measure: Mean_Reaction_Time

| Source | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| **spelling** | **Sphericity Assumed** | **859665282,002** | **1** | **859665282,002** | **258,439** | **,000** |
| | Greenhouse-Geisser | 859665282,002 | 1,000 | 859665282,002 | 258,439 | ,000 |
| | Huynh-Feldt | 859665282,002 | 1,000 | 859665282,002 | 258,439 | ,000 |
| | Lower-bound | 859665282,002 | 1,000 | 859665282,002 | 258,439 | ,000 |
| Error(spelling) | Sphericity Assumed | 462366246,248 | 139 | 3326375,872 | | |
| | Greenhouse-Geisser | 462366246,248 | 139,000 | 3326375,872 | | |
| | Huynh-Feldt | 462366246,248 | 139,000 | 3326375,872 | | |
| | Lower-bound | 462366246,248 | 139,000 | 3326375,872 | | |
| **frequency** | **Sphericity Assumed** | **67632535,302** | **1** | **67632535,302** | **35,921** | **,000** |
| | Greenhouse-Geisser | 67632535,302 | 1,000 | 67632535,302 | 35,921 | ,000 |
| | Huynh-Feldt | 67632535,302 | 1,000 | 67632535,302 | 35,921 | ,000 |
| | Lower-bound | 67632535,302 | 1,000 | 67632535,302 | 35,921 | ,000 |
| Error(frequency) | Sphericity Assumed | 261708451,948 | 139 | 1882794,618 | | |
| | Greenhouse-Geisser | 261708451,948 | 139,000 | 1882794,618 | | |
| | Huynh-Feldt | 261708451,948 | 139,000 | 1882794,618 | | |
| | Lower-bound | 261708451,948 | 139,000 | 1882794,618 | | |
| **spelling * frequency** | **Sphericity Assumed** | **649859680,502** | **1** | **649859680,502** | **232,089** | **,000** |
| | Greenhouse-Geisser | 649859680,502 | 1,000 | 649859680,502 | 232,089 | ,000 |
| | Huynh-Feldt | 649859680,502 | 1,000 | 649859680,502 | 232,089 | ,000 |
| | Lower-bound | 649859680,502 | 1,000 | 649859680,502 | 232,089 | ,000 |
| Error (spelling*frequency) | Sphericity Assumed | 389205463,748 | 139 | 2800039,308 | | |
| | Greenhouse-Geisser | 389205463,748 | 139,000 | 2800039,308 | | |
| | Huynh-Feldt | 389205463,748 | 139,000 | 2800039,308 | | |
| | Lower-bound | 389205463,748 | 139,000 | 2800039,308 | | |