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Whole-word shape effect in dyslexia

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The research question here was whether whole-word shape cues might facilitate reading in dyslexia following reports of how normal-reading children benefit from using this cue when learning to read. We predicted that adults with dyslexia would tend to rely more on orthographic rather than other cues when reading, and therefore would be more affected by word shape manipulations. This prediction was tested in a lexical decision task on words with a flat or a non-flat outline (i.e. without or with letters with ascending/descending features). We found that readers with dyslexia were significantly faster when reading non-flat compared with flat words, while typical readers did not benefit from whole-word shape cues. The interaction of participants' group and word shape was not modulated by word frequency; that is word outline shape facilitated reading for both rare and frequent words. Our results suggest that enhanced sensitivity to orthographic cues is developed in some cases of dyslexia when normal, phonology-based word recognition processing is not exploited.

It has been suggested that up to 15% of the population may suffer from some form of dyslexia. The exact figures vary due to diagnostic and cultural differences (Snowling, 2000). Developmental dyslexia has traditionally been defined as a discrepancy between reading ability and intelligence (Ramus et al., 2003). Definitions of dyslexia still emphasise difficulties with written language, although this is only one of its many manifestations (American Psychological Association, 1994). Several theories have been suggested to account for the origin of dyslexia, including phonological-deficit theory which has garnered much empirical support (Ramus et al., 2003).

The phonological-deficit theory postulates that reading problems in people with dyslexia can be ascribed to the fact that to read proficiently an individual needs to learn the way in which graphemes and phonemes correspond to enable successful decoding of text. If the correspondence between letters and sequences of letters and the sounds of letters or combinations of letters is poorly stored or retrieved, this will undermine the whole reading process (Bradley & Bryant, 1978; Vellutino, 1979). The phonological-deficit theory postulates that there is a straightforward link between this cognitive deficit and the behavioural problems seen in dyslexia (Ramus et al., 2003; Snowling, 2000). There are other non-visual theories such as the rapid auditory processing theory (Tallal, 1980) and the anchoring-deficit theory (Ahissar, 2007).

Because dyslexia has many manifestations and phenotypes, it is not surprising that in addition to phonological processing theories there is accumulating evidence for visual (Lovegrove, Bowling, Badcock & Blackwood, 1980; Stein, 2003; Stein & Walsh, 1997)

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and visual-attentional deficits (Facoetti et al., 2003) that may point to orthographic processing difficulties in dyslexia. Some studies have described dissociations between phonological and orthographic deficits in cases of dyslexia (Howard & Best, 1996; Lavidor, Johnston & Snowling, 2006; Romani, Ward & Olson, 1999; Valdois et al., 2003), thus highlighting the multi-causal nature of dyslexia and the importance of orthographic processing.

Here we examined one specific orthographic variable that was reported to affect early reading development – the outline shape of the whole word. The research question was whether word shape might facilitate reading in dyslexia, following reports that normal-reading children benefit from using this cue when learning to read (Webb, Beech, Mayall & Andrews, 2006).

Most theorists assume that there is some degree of visual featural analysis in the initial stages of reading before the focus shifts to other cognitive processes as reading progresses. The notion of featural analysis has had a long history and is part of many models of skilled reading such as the interactive activation model of word recognition (McClelland & Rumelhart, 1981) and the Local Combination Detector or LCD model (Dehaene, Cohen, Sigman & Vinckier, 2005). In addition, a recent study by Dehaene and Cohen's group (Cohen, Dehaene, Vinckier, Jobert & Montavont, 2008) explored the role of the two visual pathways, the ventral and the dorsal streams, in visual-orthographic processing. From a developmental point of view, Frith (1985) suggested that visual features (or cues) are important during the first stages of learning to read, with children initially relying on a rudimentary analysis of features. As more words are learned, this method is gradually subsumed by phonological processing, and the visual-orthographic processing is no longer the main process in skilled reading (Ehri & Wilce, 1985; Frith, 1985).

According to Mayall (2002) who employed a CaSe-MiXiNg paradigm (mixing upper and lower case) that distorted overall word shape, 6–9-year-olds appear to rely more on purely visual aspects of text initially but then develop other types of processing by roughly the age of 8 or 9 as their vocabularies increase. Other paradigms emphasising a sensitivity to certain visual features beyond letter identity within words were employed and found that children made use of distinctive visual information (Ehri & Wilce, 1985), fragmentary visual features such ascending and descending letters (Johnston, Anderson & Duncan, 1991) and holistic word cues (Masterson, Laxon & Stuart, 1992). As a whole, these findings may indicate that salient visual features such as the distinctive features of the outline shape of words could provide an effective visual cue to word recognition.

Mayall (2002), Webb et al. (2006) and Johnston et al. (1991) concluded that reliance on visual information (in the sense of sensitivity to peripheral visual features) declines when reading skills such as holistic processing give way to other strategies. The reading development model thus implies that adults who have no reading difficulties should not be affected by word shape as they do not (or rarely) use visual reading. Nonetheless, other investigators continue to claim that supraletter features such as word shape play a role in visual word recognition (e.g. Allen, Wallace & Weber, 1995; Healy & Cunningham, 1992; Healy, Oliver & McNamara, 1987). Healy and Cunningham found that the number of proofreading errors was affected by word shape in lower-case passages, but not in all-upper-case passages. Allen et al.'s (1995) holistic-biased hybrid model suggests that words can be formed either via letter-level codes or via word-level codes. This 'horse-race' model predicts that high-frequency words can be identified by the fast and frequency-sensitive word-level channel, whereas low-frequency words will be identified, on many occasions, by the frequency-insensitive letter-level channel. Perea and Rosa

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(2002) found a reliable effect for word shape, manipulated using MiXeD CaSe letters, which was greater in normal readers for low-frequency words than for high-frequency words. Interestingly these results, although reporting word shape effects, contrasted the predictions of the holistic biased hybrid model regarding word frequency (Allen et al., 1995), casting doubts regarding the role of visual-orthographic cues in adult skilled reading.

To sum up the disparities in the findings, Mayall (2002; see also Webb et al., 2006) argues that visual reading occurs only at the initial stages of reading development; hence word format cues such as whole word outline or case alternation will not affect adult readers. By contrast Perea and Rosa (2002) and Allen et al. (1995) reported word shape effects on normal adult readers, though with different theoretical accounts. Note that these contrasting views both fail to address the question of word shape effects in the case of dyslexia (in adults). Assuming that standard reading strategies are impaired in dyslexia, and in particular phonological processing, it may be the case that adults with dyslexia would tend to rely more on orthographic cues when reading (see Howard & Best, 1996), and therefore would be more affected by word shape manipulations.

To test this prediction we generated two lists of lower-case words that were matched by their length, frequency and other lexical variables. They differed only by their outline shape: the 'flat' list was composed solely of letters without ascending or descending (off-line) features, such as 'r', 'u', 's', etc., whereas the 'non-flat' list was made up of ascending and descending letters ('l', 'p', 'd'). The prediction was that readers with dyslexia would read the non-flat list better than the flat list as they make use of the word shape cues, which are more distinctive when ascending and descending letters are incorporated in them. This mild manipulation was selected rather than the more common letter case alternation (Ellis, Ansorge & Lavidor, 2007), so as to test the prediction under (more) natural word recognition conditions.

Method

Participants

Sixteen participants (10 males) formed the dyslexia group and ranged in age from 19 to 29 ($M = 22$). There were three left-handed participants. The control group was also made up of 16 participants (10 males) aged between 19 and 27 ($M = 22$). The groups were matched for gender, handedness and age. All participants had English as their first language and were students at the University of Hull.

Participants with dyslexia had to be tested within the University of Hull testing service in the previous 2 years and have had a history of reading problems. Control participants reported no reading problems at any stage in their lives. In addition, both groups were assessed on a battery of literacy and cognitive skills as detailed below.

Assessment battery

Literacy skills. One of the subtests from the Wide Range Achievement Test (WRAT; Jastak & Wilkinson, 1993) was used to measure word reading. The test consists of a list of words organised from easy to hard to read.

Both subtests of the Test of Word Reading Efficiency (TOWRE) were also used (Torgesen, Wagner & Rashotte, 1999). The sight reading efficiency test consisted of a list

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of words that need to be read as fast and accurately as possible within 45 seconds. The phonetic decoding efficiency subtest consisted of a list of pronounceable nonwords (pseudowords). This task also requires participants to read as fast and accurately as possible within 45 seconds.

Phonological skills. *Rapid naming*: The rapid object naming task from the Comprehensive Test of Phonological Processing (CTOPP, Wagner, Torgesen & Rashotte, 1999) comprised two cards with pictures of objects (e.g. boat, star, pencil, etc.). Participants were asked to name the objects in order, from left to right, as fast and accurately as they could. Response times and errors were recorded.

Spoonerisms: The spoonerism task (Perin, 1983) consisted of a list of word pairs. The task was to swap the words' initial phonemes (e.g. Key-Chain/Chee Kain). There were 18 word pairs taken from Perin (1983). Response times and errors were recorded.

Cognitive ability: Two subtests of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1997) were used to assess verbal and nonverbal skills.

Verbal ability: The vocabulary subtest requires participants to give the meaning of 42 words presented in a list. The responses were scored according to the goodness of fit of the response to standard responses (i.e. scores of 0, 1 or 2 points). Words are increasingly difficult and the test is discontinued after a series of zero responses (i.e. stop rule).

Nonverbal ability: In the matrix of reasoning subtest, participants are presented with pictures where a piece is missing. Participants are required to observe the picture and need to say which of a series of options fits the missing bit. This subtest has a stop rule as well.

Cognitive processing skills. Working memory test. The digit span subtest from the Wechsler Adult Intelligence Scale III (WAISIII; Wechsler, 1997) battery was used. In this test, the examiner presents a random sequence of digits and the participant has to repeat it. There are two tasks in this subtest. The digit forward task requires the participants to repeat the digits in the same order they were presented. In the backward task, the sequence of digits has to be reversed. The number of digits increases by one for every successful trial. The score reflects the maximum number of digits that were correctly repeated.

Results of group comparisons

Group means, standard deviations and significance values are presented in Table 1. As expected, the dyslexia group had poorer performance than controls on the WRAT reading scores, $t(30) = 6.35$, $p < .001$, the TOWRE for words, $t(30) = 3.88$, $p < .001$, the TOWRE for nonwords, $t(30) = 7.40$, $p < .001$. There were no differences for verbal and nonverbal skills, $p > .1$. The only predicted difference that showed a trend rather than a clear difference was the digit span test, $t(30) = -1.60$, $p = .068$.

Stimuli: There were two lists of stimuli with 40 words of four to six letters each (see Appendix A). Half of the strings were high-frequency words (mean frequency = 126 according to the Celex Database; Baayen, Piepenbrock & van Rijn, 1993) and the other half were low-frequency words (mean = 19). The words in the lists were balanced across several parameters; that is, frequency (Celex), orthographic neighbourhood (according to the English Lexicon Project [ELP]; Balota et al., 2007) and length. Crucially, the words in the two lists were matched for RT to a lexical decision task conducted with these words as collected from 817 subjects (Balota et al., 2007). The fact that the lists were

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Table 1. The literacy and cognitive skills comparisons for participants with dyslexia and controls.

			Dyslexia		Control		
			M	*SD*	*M*	*SD*	Comparison
Literacy skills	WRAT	Reading	103	7	112	5	$p < .001$
	TOWRE	Words	83	8	92	7	$p < .001$
		Nonwords	85	10	105	9	$p < .001$
Phonological skills	Rapid naming		7	3	11	2	$p < .001$
	Spoonerism		9	5	17	3	$p < .001$
Cognitive ability	Verbal skills		58	11	59	9	$p > .1$
	Nonverbal skills		48	9	48	7	$p > .1$
	Abbreviated scales IQ		107	13	107	11	$p > .1$
Cognitive processing skills	Working memory	Digit span	9.1	2.1	10.7	2.8	$p = .07$

TOWRE, Test of Word Reading Efficiency; WRAT, Wide Range Achievement Test.

matched for normative RT implies that even if there are additional lexical parameters that are not matched between the lists, any difference in RT found in the current experiment can be safely interpreted as reflecting differences in the manipulated experimental conditions but not confounding factors. Eighty nonwords, orthographically legal but not pseudohomophones, matched in length and 'flatness' to the words, were generated to allow lexical decision task, and their lexical properties were carefully matched based on the ELP-rich database (Balota et al., 2007). Half of the nonwords included only flat letters, and the other half non-flat letters. The average number of letters (4.87 in the flat list, 5.02 letters in the non-flat list), mean orthographic neighbourhood (five in each group), mean bigram frequency (1,662 and 1,685, respectively) and mean RT to a lexical decision task with these nonwords as collected from 817 subjects (Balota et al., 2007) that were 761 ms in the flat list and 768 ms in the non-flat list, did not differ significantly on any property. All letter strings were presented in Courier New font size 15 points.

Procedure

All the tests were performed in a single session, which lasted approximately 50 minutes. The experimental task was completed first, which was then followed by the assessment tasks. Each participant completed a total of 80 word and 80 nonword trials on the lexical decision task. All stimuli were presented in lower case; half had no ascending or descending letters (i.e. 'flat') and the rest contained such letters ('non-flat'). Words and nonwords, of high or low frequency and with a flat or a non-flat outline were presented in a random order in screen centre.

Each trial began with a fixation cross (+) appearing in the centre of the screen for 500 ms. A word or nonword was then presented until a response was made, or until 3 seconds had elapsed without a response. Participants were asked to decide as quickly and as accurately as possible whether each stimulus was a word or a nonword and to respond by pressing one of two keys on a standard QWERTY keyboard with the index or middle finger of their right hand. Half the participants made 'word' responses by pressing the N key and 'nonword' responses by pressing the V key. The remaining participants made 'word' responses by pressing the V key and 'nonword' responses by pressing the N key.

The presentation of the stimuli and recording of accuracy and RTs was controlled by Eprime v1 software. The experimental session began with 12 practice trials in which 6

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words and 6 nonwords were presented centrally (half flat, half non-flat). Filler words and nonwords were used for these practice trials.

Results

Two mixed-design analyses were carried out with stimuli lexicality (high-frequency word, low-frequency word and nonword), stimuli shape (flat or non-flat) as the within-subject variables and group (dyslexia, controls) as the between-subject variable, one for RT (for correct responses) and one for accuracy. These $F1$ analyses were followed by the corresponding item analysis.

A main effect of lexicality was found, $F1(2, 60) = 59.79$, $p < .0001$; $F2(1, 154) = 4.21$, $p < .05$. Responses to nonwords (mean = 865 ms) were the slowest, followed by faster RTs to rare words (mean = 753 ms) and fastest RT to frequent words (733 ms). There was a nearly significant interaction between lexicality and group, $F1(2, 60) = 3.01$, $p = .057$; $F2(1, 154) = 2.14$, *ns*. Bonferroni post hoc comparisons ($p < .05$) did not reveal any significant differences; however, the patterns reflected a greater advantage of 34 ms for frequent words compared with rare words in the dyslexia group, whereas word frequency had no significant effect in the control group (11 ms advantage). Nonwords were processed faster in the control group (841 ms) when compared with the dyslexia group (889 ms). However, these are only trends as they failed to reach significance.

The novel finding of this study was the significant three-way interaction between stimuli shape, lexicality and group, $F1(2, 60) = 6.04$, $p < .01$; $F2(2, 154) = 4.12$, $p < .01$. Because the predictions and the experimental design regarded words only, the interpretation of the three-way analysis required separate further analysis for words (of high and low frequency) and nonwords. For words, there was a significant interaction of shape and group, $F1(1, 30) = 6.32$, $p < .05$; $F2(1, 76) = 4.51$, $p < .05$. Bonferroni post hoc comparisons revealed only one significant difference between participants' groups and word shape categories: while there was no word shape effect in the control group, non-flat words (mean = 727 ms) were responded to faster than flat words (746 ms) in the dyslexia group. This pattern is plotted in Figure 1. For nonwords, there was a main effect of group, $F1(1, 30) = 8.49$, $p < .01$; $F2(1, 76) = 6.34$, $p < .05$, reflecting that control participants responded faster (841 ms) than participants in the dyslexia group (889 ms). Nonword shape, however, did not affect latency in any group.

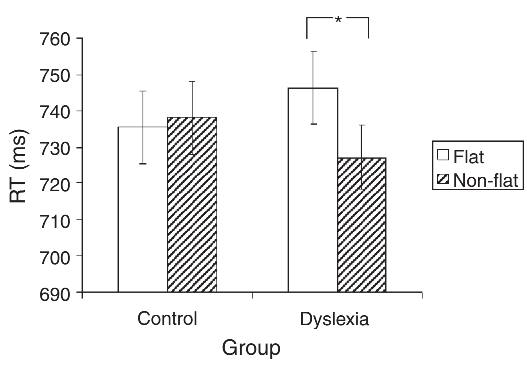

Figure 1. Lexical decision latencies (and error bars) to correct words as a function of word shape and participants' group.

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The accuracy measure did not reveal many effects. There was a significant group effect, $F1(1, 30) = 13.1$, $p < .01$; $F2(1, 154) = 6.41$, $p < .01$, with higher accuracy (91.7%) in the control group compared with the dyslexia group (82.5%). There was a significant interaction of lexicality and group, $F1(2, 60) = 5.35$, $p < .01$; $F2(1, 154) = 2.51$, *ns*. Bonferroni post hoc comparisons ($p < .05$) revealed that while the participants in the dyslexia group had roughly the same accuracy level for all stimuli types, in the control group responses to nonwords (mean = 84.5%) were significantly less accurate than to rare or frequent words (both were responded to with 97% accuracy). Stimuli shape, however, did not affect accuracy of lexical decision: flat items were responded to with 88.3% accuracy (94.3% for control, 82.3% for dyslexia group), with similar accuracy for non-flat items (87.9%) with 92.1% correct responses in the control group and 82.3% in the dyslexia group.

No other significant main effects or interactions were found regarding accuracy.

Discussion

We manipulated word shape cues in order to assess whether visual featural word recognition takes place in adult reading, in typical and atypical (dyslexic) readers. Facilitation effects of distinctive word shape (Mayall, 2002) were found only for readers with dyslexia but not for typical readers. Both groups were faster and more accurate for frequent words; however, word frequency did not modulate the selective word shape effects in the dyslexia group. Word shape did not affect processing of nonwords, which suggests the visual-orthographic analysis involves top-down support during word recognition (Lavidor et al., 2006). These results are the first to demonstrate subtle word shape effects in a group of adults with dyslexia, adding therefore to Mayall's (2002) studies (see also Webb et al., 2006) with children that predicted use of visual word outline only in impaired but not normal reading.

Our findings did not replicate the use of orthographic cues in the control group (Perea & Rosa, 2002); however, this could be due to the subtler manipulation of word shape we used compared with case alternation or all upper-case presentation (Allen et al., 1995). Previous studies that employed extreme manipulations of word shape reported sensitivity to visual word format in typical readers (Ellis et al., 2007).

Arguably, people with dyslexia are relatively advantaged in processing non-flat words that might have a more distinctive appearance due to a preference for global, holistic processing that capitalises on the coarse coding of orthography–phonology mappings (Lavidor et al., 2006). Such a processing strategy is indeed the likely outcome of learning to read in the absence of good phonology or the capacity to create fine-grained mappings between graphemes and phonemes (Harm, McCandliss & Seidenberg, 2003). If, as is widely accepted, deficits at the level of phonological representation in children with dyslexia compromise the mappings created between phonology and orthography in the phonological pathway (Harm & Seidenberg, 1999; Snowling, 2000), these mappings will not be at the fine segmental level that is optimal for reading in English. The argument is that the three representational forms of words (phonological, orthographic and semantic) capture different proportions of processing, and the balance between them may be shifted in dyslexia. As our study shows, there might be more reliance on orthographic cues in dyslexia, hence the larger word shape effect reported here.

Other studies have highlighted the importance of the analysis of visual features. Gibson, Gibson, Pick and Osser (1962) showed that each letter of the alphabet is composed of a pattern of different visually distinctive features, and proposed that

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detecting distinctive features within words is a key factor in children's perception of words. Beech and Mayall (2005) concluded that, far from being evenly distributed, there is a concentration of stimulus information on the periphery of words; hence, priming words with these areas has a more potent effect than priming words with their internal features, which are relatively more impoverished. Moreover, as a result of this richer informational composition, readers have a predisposition to process outer information (i.e. the external shape of the word) over internal information (the visual information inside the physical borders of the printed word). Perhaps, as Beech and Mayall (2005) suggested, prior access to a word's external features is an obligatory process in the course of word recognition, but it also seems that the outer features of words contain elements that are more potent.

Previous research has found that salient visual features such as the distinctive features of the outline shape of words provide an effective visual cue to word recognition in children when beginning to read (Ehri & Wilce, 1985; Johnston et al., 1991; Masterson et al., 1992; Mayall, 2002). In addition, Mayall (2002), Webb et al. (2006) and Johnston et al. (1991) concluded that reliance on visual information (in the sense of sensitivity to peripheral visual features) declines when reading skill as holistic processing gives way to other strategies. The current results show that this visual processing continues to have an effect in cases of impaired reading in adults, but not in typical readers.

It is important to note that the word shape manipulation we conducted was very subtle and did not alter the appearance of the word, unlike previous studies that employed alternating case (Perea & Rosa, 2002), all upper-case letters (Allen et al., 1995) or other explicit visual manipulations (Webb et al., 2006). Yet even this implicit cue of word shape, which is more distinctive in non-flat than flat words, was sufficient to make word recognition easier for readers with dyslexia. Overall, the control group was more accurate than the dyslexia group; however, for words with ascending and descending features, readers with dyslexia improved their lexical decision speed compared with flat words and did not differ from controls. The high accuracy rates in the control group in all conditions probably reflect the ease of the task, as there was no time limit and words were presented until responses were recorded. The subtle manipulation we employed explains the lack of potential word shape effects on typical reading reported previously (e.g. Allen et al., 1995; Healy & Cunningham, 1992; Healy et al., 1987; Perea & Rosa, 2002).

Thus, in a typical healthy reading development, the effects of visual word features have only a minimal effect on performance in a lexical decision task, because the task utilises efficient mappings between orthographic and phonological representations. However, when the development of such mappings is compromised (as is the case in developmental dyslexia), we can expect anomalies in the way orthographic and phonological factors affect reading.

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Appendix A

Table A1. Word stimuli; norms for RT are taken from the ELP project (Balota et al., 2007).

Flat word	Length	Freq.	Ortho_N	RT	Non-flat word	Length	Freq.	Ortho_N	RT
Access	6	24	0	677	Abrupt	6	18	0	690
Accuse	6	10	0	626	Ballet	6	45	6	622
Answer	6	152	0	572	Belt	4	29	12	595
Avenue	6	46	1	644	Bishop	6	18	0	588
Camera	6	36	0	631	Bold	4	21	12	661
Cancer	6	25	5	616	Chip	4	17	8	579
Care	4	162	24	580	Date	4	103	17	637
Common	6	223	0	602	Deadly	6	19	1	592
Cone	4	13	18	670	Design	6	114	1	561
Core	4	37	23	628	Direct	6	129	0	587
Corner	6	115	3	683	Disk	4	25	5	647
Crew	4	36	5	591	Drying	6	29	3	671
Earn	4	16	6	585	Employ	6	12	0	678
Ease	4	42	6	616	Fall	4	147	12	709
Excess	6	42	1	605	Father	6	183	4	656
Excuse	6	27	1	625	Fish	4	35	4	574
Manner	6	124	4	641	Gently	6	31	2	615
Mass	4	110	15	594	Hang	4	26	10	602
Mean	4	199	9	634	Hidden	6	20	1	592
Mere	4	47	5	727	Hold	4	169	11	613
Mess	4	22	9	615	Island	6	167	1	608
Move	4	171	9	611	Keys	4	34	1	616
Museum	6	32	0	698	Lead	4	129	12	585
Near	4	198	13	582	Leaf	4	12	6	559
News	4	102	4	636	Liking	6	11	4	756
None	4	108	13	621	Living	6	194	6	611
Noon	4	25	8	619	Myself	6	129	0	627
Reason	6	241	1	579	Path	4	44	7	603
Rescue	6	15	0	584	Pink	4	48	14	568
Season	6	105	1	588	Pretty	6	107	0	638
Secure	6	30	0	680	Sigh	4	11	4	613
Series	6	130	1	657	Simply	6	170	3	613
Severe	6	39	2	659	Superb	6	14	0	701
Soon	4	199	7	683	Talk	4	154	8	749
Sore	4	10	15	585	Tide	4	11	10	637
Summer	6	134	3	670	Toilet	6	13	1	630
Warn	4	11	12	592	Type	4	200	2	630
Worn	4	23	12	608	Wall	4	160	13	563
Zone	4	11	8	575	Yearly	6	12	3	613
Resume	6	16	0	577	Play	4	200	6	664
Total	5	77.7	6.1	624	Total	5	75.25	5.25	626

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