

Phonological decoding or direct access?

Regularity effects in lexical decisions of Grade 3 and 4 children

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Abstract

Learning to read fluently involves moving from an effortful phonological decoding strategy to automatic recognition of familiar words. However, little is known about the timing of this transition, or the extent to which children continue to be influenced by phonological factors when recognising words even as they progress in reading. We explored this question by examining regularity effects in a lexical decision task, as opposed to the more traditionally-used reading aloud task. Children in Grades 3 and 4 made go/no-go lexical decisions on high- and low- frequency regular and irregular words that had been matched for consistency. The children showed regularity effects in their accuracy for low frequency words, indicating that they were using phonological decoding strategies to recognise unfamiliar words. The size of this effect was correlated with measures of reading ability. However, we found no regularity effects on accuracy for high frequency words or on response times for either word type, suggesting that even eight-year-old children are already relying predominantly on a direct lexical strategy in their silent reading of familiar words.

Keywords: Orthographic learning, phonological decoding, reading development, silent reading, lexical decision

Learning to read fluently involves moving from effortful phonological decoding to automatic recognition of familiar words. It has been proposed that this initial mapping of letters onto sounds is the causal mechanism which enables beginning readers to build up orthographic representations in their mental lexicons (Share, 1995). The presence of such orthographic representations then allows the reader to recognise words effortlessly and automatically, while a phonological decoding strategy will still be required for any word (or nonword) that is unfamiliar. This theory of reading development is compatible with the dual-route theories of reading (e.g., M. Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), which state that automatic orthographic retrieval can be achieved via a lexical cognitive route, while a sublexical procedure is required for phonological decoding.

A commonly used measure to estimate the degree of reliance on phonological decoding as opposed to pure orthographic retrieval is the *regularity* effect. Irregular words are words such as *yacht*, for which the pronunciation conflicts with the letter-to-sound rules. According to the dual-route theory, the output for irregular words from phonological decoding conflicts with the correct entry in the mental lexicon, resulting in slower reaction times (RTs) and/or more errors than for regular words in reading aloud. In studies with English readers, this effect is only found for words of low frequency, presumably because the orthographic representations for high frequency words are well-established in the orthographic lexicon and can be retrieved before the slower phonological strategy can interfere (Waters, Seidenberg, & Bruck, 1984).

Although regularity effects fall naturally out of a dual-route framework, the alternative triangle model of reading (Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996) also predicts effects of the ease with which words can be phonologically decoded. This model proposes that the pronunciation of a word can

either be computed through the orth→phon pathway, which maps the orthography directly onto the phonology of a word, or indirectly, via semantics (orth→phon→sem pathway). As the triangle model does not distinguish between a lexical and sublexical procedure within the orthography-to-phonology route, regularity is not viewed in terms of violations of a set of letter-sound correspondence rules. Instead, the model stresses the importance of consistency. Inconsistent words are words that have bodies that are pronounced differently in different words (e.g., “have” – “save”). A computer simulation of the triangle model showed a frequency-by-consistency interaction, which was driven by slower processing of low-frequency inconsistent words by the orth→phon→sem pathway (Harm & Seidenberg, 2004).

A majority of behavioural studies on the regularity effect have employed a reading aloud task. However, reading aloud requires the reader to activate and produce the phonology of a word and so may be subject to greater influences of phonological decoding than would be the case in silent word recognition. Indeed, in adults, the effect of regularity disappears or becomes negligible if a lexical decision task, requiring a decision about whether an item is a word or nonword, is used instead of reading aloud (Waters, et al., 1984). This indicates that skilled readers rely predominantly on quick, orthographic lexical retrieval in silent reading.

In contrast, young readers, who are still in the process of building up an orthographic lexicon, might be expected to rely more heavily on a phonological decoding strategy even when performing silent reading tasks such as lexical decision. Specifically, they may not have orthographic lexical entries for many words, and so may make decisions about lexical status based on phonologically decoding them and then judging if the output matches a word in their spoken vocabulary. In addition, it may be that the orthographic representations that have been acquired by younger readers are

still weak and take relatively long to get activated. In this case we might also expect the output of phonological decoding to influence their response times. Given that the naturalistic act of reading typically involves silent reading and comprehension, rather than reading aloud, this issue deserves exploration.

To date, there have been four studies of lexical decision in children aged 9 to 12 and all have found a regularity effect (Barron, 1980; V. Coltheart, Laxon, Keating, & Pool, 1986; Schlapp & Underwood, 1988; Waters, et al., 1984). However, these studies did not control for the consistency of their item set, which is a potential confounding variable. Consistency is correlated with regularity, but there is disagreement amongst proponents of different theoretical frameworks as to where and how consistency effects arise. As noted above, triangle models consider such effects as being a function of the phonological O->P route. However, others have hypothesised that they may be an indicator of orthographic, rather than phonological processing, because highly consistent words activate representations of orthographically similar items or “neighbours” in the mental lexicon (Andrews, 1982; Glushko, 1979). Therefore, there remains some question as to whether the regularity effect in these four studies reflects the use of a phonological decoding strategy in children.

Furthermore, three of the studies above have also explored the regularity effect as a function of reading ability and have come to somewhat contradictory conclusions. Both Barron (1980) and Schlapp and Underwood (1988) hypothesised that the regularity effect would be smaller in poor readers, because they are impaired in phonological processing and are forced to compensate for their lack of decoding skills by building up an orthographic lexicon via a visual mechanism. This hypothesis was supported by their data. Waters et al., (1984), on the other hand, found a larger regularity effect in poor readers. This is consistent with the theory that orthographic

representations cannot be built up without previously decoding the word (Share, 1995). Thus, poor decoders cannot build up orthographic entries, forcing them to continue to rely on their impoverished phonological decoding skills.

The aim of the current study was to explore further to what extent developing readers rely on direct orthographic access in silent reading by examining regularity effects in a lexical decision task. Children in Grades 3 and 4 performed lexical decisions on high and low frequency words and we examined both their accuracy and response times. The regular and irregular words in our item set all had consistent bodies, so as to control for the potential confounding effects of this factor. We also included pseudohomophones (e.g., “wurm”) among the nonword foils. A phonological decoding strategy is maladaptive in this condition, as it would result in incorrectly accepting an item as a real word¹. Finally, we examined the relationship between the size of the children’s individual regularity effects and their reading and oral vocabulary skills.

A regularity effect for accuracy would indicate that lexical entries for at least some of the items had not yet been established by the children, resulting in reliance on phonological decoding to perform the lexical decision, and consequent errors on the irregular words. We expected that this effect would be stronger for low frequency than for high frequency words, and stronger for less advanced readers than for more advanced readers. A regularity effect in correct response times would imply that developing readers are still influenced by the output of phonological decoding when performing lexical decisions, even when a word has a representation in the mental lexicon. Again, this would be most likely to be the case for low frequency words and for

¹ While it could be argued that this may have resulted in the children adopting a strategy different from that used in their normal reading, we note that developing readers are exposed to many unfamiliar words that sound like real words as they build their sight vocabularies, so this may not be particularly artificial for them.

less advanced readers. If there were no regularity effect in response times, this would suggest that, after an entry has been established in the mental lexicon, there is little or no phonological influence on word recognition, even in developing readers.

Method

Participants

Sixty Australian children from Grades 3 (9 girls, 21 boys,) and 4 (19 girls, 11 boys) participated. We chose Grade 3 as the youngest group, as children at this level typically have well-developed phonological decoding skills, but are still in the process of building a sight vocabulary. All were participants of a larger longitudinal study, and had also been measured on a standardised reading test, the Castles and Coltheart 2 (CC2; Castles et al., 2009), as well as their nonverbal intelligence (kbit; Kaufman & Kaufman, 1990) and receptive vocabulary (ACE; Adams, Cooke, Crutchley, Hesketh, & Reeves, 2001) (see Table 1). The children were within normal range on all these measures.

(Table 1 about here)

Materials

The stimulus set included 60 words and 60 nonword foils. All were monosyllabic and occurred in the Children's Printed Word Database (CPWDB; Masterson, Stuart, Dixon, Lovejoy, & Lovejoy, 2003). The words differed on regularity and frequency (low frequency average = 20.93 per million; SD = 20.25, and high frequency = 249.53; SD = 133.55), resulting in four groups of 15 items each. Regularity was defined as compliance with English grapheme-phoneme correspondence rules (Rastle & Coltheart, 1999). The conditions were matched on letter length and orthographic N size. Orthographic N size

and frequency measures were based on the CPWDB. Across regularity, the conditions did not differ in terms of age of acquisition (Kuperman, Stadthagen-Gonzalez, & Brysbaert, in press) or bigram frequency (Davis, 2005). We used consistent words (Ziegler, Stone, & Jacobs, 1997). Note that several items were inconsistent according to this list, however, they had very few enemies that are be unlikely to be familiar to young children (e.g., “ache” which has the enemy “cache”). We used two types of nonwords: ‘typical’ nonwords (NW) and pseudohomophones (PsH). NWs were orthographically legal letter strings in English created by the non-word generator Wuggy (Keuleers & Brysbaert, 2010). The pseudohomophones were taken from Davis, Castles & Iakovidis (1998) and Wuggy. All items are presented in the appendix.

The go/no-go lexical decision task has been found to be preferable to the more commonly used yes/no task when conducting experiments with developing readers (Moret-Tatay & Perea, 2011). We therefore instructed the children to press the spacebar as quickly as they could when they read a word. When they read a nonword (‘a nonsense, or a silly word’) they were instructed to wait until it disappeared. In addition it was stressed that there were also ‘nonsense’ words that sounded like real words and that the children were to only press the spacebar when the word was also correctly spelled.

The stimuli were presented in the middle of a 15-inch LCD screen of a laptop computer in random order. Twenty practice items (10 words, 5 nonwords and 5 pseudohomophones) preceded the target items. The words were presented in 46-point lowercase, black Arial font on a white background, after a 750ms fixation cross. An item remained on the screen for 2500 ms or until the child made a response. The RTs were measured as the time between the appearance of the item and the child’s response.

Procedure

The standardised reading tasks and the lexical decision experiment were administered at the same time, at the end of the academic year. All children were tested in a quiet room at their school in sessions of approximately 15-20 minutes. The nonverbal intelligence and receptive vocabulary data had been collected one year earlier.

Results

Trimming

For the RT analyses, only correct and valid responses (< 400 milliseconds and < 2SDs from a child's individual mean score for each of the four conditions) were included. The total percentage of invalid trials was less than 5%. The mean error percentage was 11.67 (SD = 8.57) for typical nonwords and 18.89 (SD = 15.89) for pseudohomophones, which was a significant difference, $t(59) = -5.59, p < .001$.

We examined with a repeated measures ANOVA whether the children showed a regularity effect in terms of accuracy and response times (RT), whether the regularity effect was stronger for low frequency words than for high frequency words and whether the regularity effects were stronger for the Grade 3 children than for the Grade 4 children. The means and standard deviations for all frequency by regularity conditions per Grade are presented in Table 2.

(Table 2 about here)

In accuracy, there was a significant main effect of Regularity across subjects, $F_1(1, 58) = 35.84, p < .001, \eta^2_p = .38, F_2(1, 56) = 2.47, p = .12, \eta^2_p = .042$, and a significant

main effect of Frequency across subjects and items, $F_1(1, 58) = 143.09, p < .001, \eta^2_p = .71, F_2(1, 56) = 27.43, p < .001, \eta^2_p = .33$. Lexical decision accuracy tended to be higher for regular than for irregular words and was higher for high frequency words than for low frequency words. Across subjects, the interaction between Regularity and Frequency was also significant, $F_1(1, 58) = 26.54, p < .001, \eta^2_p = .31, F_2(1, 56) = 2.75, p = .10, \eta^2_p = .047$, indicating that the size of the regularity effect differed for high frequency and low frequency words (see Figure 1). Follow-up analyses showed that the regularity effect was not significant for high frequency words, $F_1 < 1, ns, F_2 < 1, ns$, but was significant for low frequency words across subjects, $F_1(1, 58) = 35.29, p < .001, \eta^2_p = .37$, and just failed to reach significance across items, $F_2(1, 56) = 2.77, p = .11, \eta^2_p = .09$. We only found a significant main effect over items for Grade, $F_1(1, 58) = 1.26, p > .10, F_2(1, 56) = 5.64, p < .05, \eta^2_p = .092$ and no significant interactions between Grade and either Regularity or Frequency, $F_1 < 1, ns, F_2 < 1, ns$. This means that although the overall accuracy of Grade 4 children tended to be higher than that of Grade 3 children, regularity and frequency effects did not differ across the two grades.

(Figure 1 about here)

For RTs we found significant main effects of Grade, $F_1(1, 58) = 4.27, p < .05, \eta^2_p = .069, F_2(1, 56) = 49.39, p < .001, \eta^2_p = .47$ and Frequency, $F_1(1, 58) = 163.86, p < .001, \eta^2_p = .74, F_2(1, 56) = 70.26, p < .001, \eta^2_p = .56$. Overall, Grade 4 children were faster than Grade 3 children and children were faster in making lexical decisions about high frequency words than low frequency words. There was no main effect of Regularity for

the RTs, $F_1(1, 58) = 1.21, p > .10, ns, F_2 < 1, ns$ and no interaction with Frequency, $F_1 < 1, ns, F_2 < 1, ns$.

We then collapsed the data across Grade and looked at the relation between the size of the regularity effect found on accuracy for the low frequency words (regular word reading accuracy – irregular word reading accuracy) and the raw accuracy scores on the regular, irregular and nonword subtests of the Castles and Coltheart 2. Because the relation between the regularity effect size and reading level may be confounded by the age of the children or their receptive vocabulary, we also examined the correlation between the regularity effect size, age and vocabulary (raw scores). The correlations are presented in Table 3.

(Table 3 about here)

The significant negative correlations between all three reading accuracy measures and the regularity effect size for low frequency words indicate that the regularity effect on accuracy for low frequency words is larger for children with low reading scores than for children with high reading scores. However, there were no significant correlations between the size of the regularity effect and age or vocabulary.

Discussion

The current study is the first to explore regularity effects on children's lexical decision responses after controlling for consistency. Previous studies have found a small regularity effect without controlling for consistency, and thus may not have directly assessed the influence of phonological decoding on silent reading (Barron, 1980; V. Coltheart, et al., 1986; Schlapp & Underwood, 1988; Waters, et al., 1984). In

addition, the two low-frequency conditions were matched on age-of-acquisition, orthographic N-size, and bigram frequency, meaning that any differences between the two conditions could not have been caused by differences in orthographic complexity or oral familiarity.

We found no regularity effect for high frequency words in either accuracy or response times. The lack of such an effect indicates that children as young as 3rd Grade already rely predominantly on automatic orthographic retrieval in silent reading of familiar words. The output of their phonological decoding, at least at the level of grapheme-to-phoneme translation, apparently has no influence on their responding. These findings are in line with the results of lexical decision studies of length effects, which also report that phonological decoding in silent reading tasks is secondary to orthographic processing in 3rd grade children, but not 2nd graders (e.g., Martens & de Jong, 2006; Zoccolotti et al., 2005).

For the low frequency items, a regularity effect was found in accuracy only, which most likely reflects the content of the orthographic lexicons of the children. Because a proportion of the regular and irregular words were not familiar to them, they were required to rely on the output of phonological decoding to make a lexical decision. Correctly decoding a regular word via letter-sound rules will still result in a correct “Yes” response, as the blended phonological output coincides with an entry in the child’s spoken vocabulary, and will also activate the corresponding semantic information. However, decoding an irregular word via letter-sound rules (even when done correctly) will result in a regularised pronunciation, which seems unfamiliar to a child (and does not map onto semantic information either), leading to incorrect “No” responses. As well as benefiting from the assistance of on-line phonological decoding, it is also possible that regular words are simply more strongly represented in the orthographic lexicons of

children than irregular words. This imbalance would be predicted by the self-teaching hypothesis, given that successful phonological decoding is seen as the primary pathway to the acquisition of orthographic representations (Share, 1995). It is also supported by the results of recent learning studies (e.g., Wang, Castles, & Nickels, in press).

The failure to find any regularity effect on response times for low frequency words suggests that once an orthographic entry is established, the word can be retrieved quickly and automatically independent of phonological decoding. That even relatively uncommon words can be automatically retrieved is consistent with the idea that the acquisition of orthographic representations occurs in an item-based, all-or-none fashion (Share, 1995) or at least that the point at which a threshold activation level for an orthographic representation is reached is all-or-none. There was no evidence of a “graded” effect, such that the speed of children’s correct responses to less-familiar words remained subject to the influence of phonological decoding factors.

A further aim of this study was to explore the size of the regularity effect as a function of the children’s reading ability, as previous research has reported inconsistent results on this issue (Barron, 1980; Schlapp & Underwood, 1988; Waters, et al., 1984). Consistent with Waters et al (1984), we showed that the size of the regularity effect on accuracy for low frequency words was correlated with all measures of reading ability, including nonword reading. This correlation suggests that, somewhat paradoxically, children with poor phonological decoding skills rely more heavily on phonological decoding than children with good such skills. However, this finding makes sense if it is proposed that entries in the orthographic lexicon are typically formed via phonological decoding (Share, 1995). Thus, children with weak orthographic lexicons, which are a result of poor phonological decoding skills, are forced to rely on their, albeit poor, phonological decoding for the majority of words. The correlation between phonological

decoding skills and orthographic knowledge of irregular loanwords has previously also been demonstrated in German-speaking children (Wimmer, Mayringer, & Landerl, 2000).

The present study was carried out within the broad framework of the dual route theory, and the findings are clearly consistent with this model (M. Coltheart, et al., 2001). However, we do not rule out that the findings could also be accounted for within a triangle model (Harm & Seidenberg, 2004; Plaut, et al., 1996) of reading. This model explains the frequency effect in terms of connection strength between orthographic, phonological and semantic units. The interaction between frequency and regularity could possibly be a result of weaker orth→sem connections for the low frequency irregular words as compared to the high frequency and regular words. However, given that there are no word-specific lexical representations, it remains a challenge for the triangle model to specify what sources of information are being used to generate the children's lexical decision responses. Because we included pseudohomophones in the lexical decision task, phonological familiarity (i.e., the phon->orth route in the triangle model) would not have been a reliable source for lexical decision. Therefore, it may need to be proposed that the children's decisions were based on semantic activation alone (i.e., the orth -> sem route, see e.g., Plaut, 1997). However, the low frequency regular and irregular words did not differ on frequency or age of acquisition. As a result, within a triangle model perspective, it is not immediately obvious why this should have resulted in poorer performance for the low frequency irregular words.

In summary, while it is clear that phonological decoding is an essential foundation of early reading acquisition, our results suggest that, by Grade 3, typically-developing children are reading familiar words predominantly via direct orthographic retrieval.

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Figures and tables

Table 1

Performance of Grade 3 and 4 children on standardised tests of reading, language and general ability

	Grade 3 (N=30)			Grade 4 (N=30)		
	Mean	SD	Range	Mean	SD	Range
Age (Y;M)	8;11	0;4	8;4-9;7	9;11	0;4	9;4-10;9
CC2 – regular (z score) ⁺	.15	.99	-1.53-2.37	.10	1.38	-2.12-2.99
CC2 – irregular (z score)	.17	.85	-2.07-1.71	-.37	.91	-1.82-2.00
CC2 – nonwords (z score)	-.13	.83	-2.29-1.21	-.47	.97	-2.23-2.63
Nonverbal IQ (SS)	101.70	15.32	73-132	104	18.35	61-129
Receptive vocabulary (SS)	8.63	2.53	4-13	7.33	2.91	3-12

Notes:

⁺ *Nonverbal IQ (Kbit) scores has a mean of 100 and SD of 15, CC2 scores have a mean of 0 and a SD of 1, and Receptive vocabulary (ACE) scores have a mean of 10 and a SD of 3*

Regularity Effect in Lexical Decisions

Table 2

Mean error percentages (and standard deviations) and mean RTs (and standard deviations) in milliseconds for all frequency by regularity conditions per Grade

	Accuracy				RT			
	High frequency		Low frequency		High frequency		Low frequency	
	Regular	Irregular	Regular	Irregular	Regular	Irregular	Regular	Irregular
Grade 3	5.29 (8.06)	4.43 (6.45)	19.43 (13.58)	30.57 (19.74)	888 (191)	906 (219)	1076 (277)	1104 (285)
Grade 4	2.84 (6.35)	3.27 (4.34)	15.26 (12.21)	28.12 (18.35)	805 (139)	789 (160)	969 (228)	991 (187)
Total	4.06 (7.30)	3.85 (5.48)	17.35 (12.97)	29.35 (18.94)	846 (171)	847 (199)	1023 (258)	1047 (245)

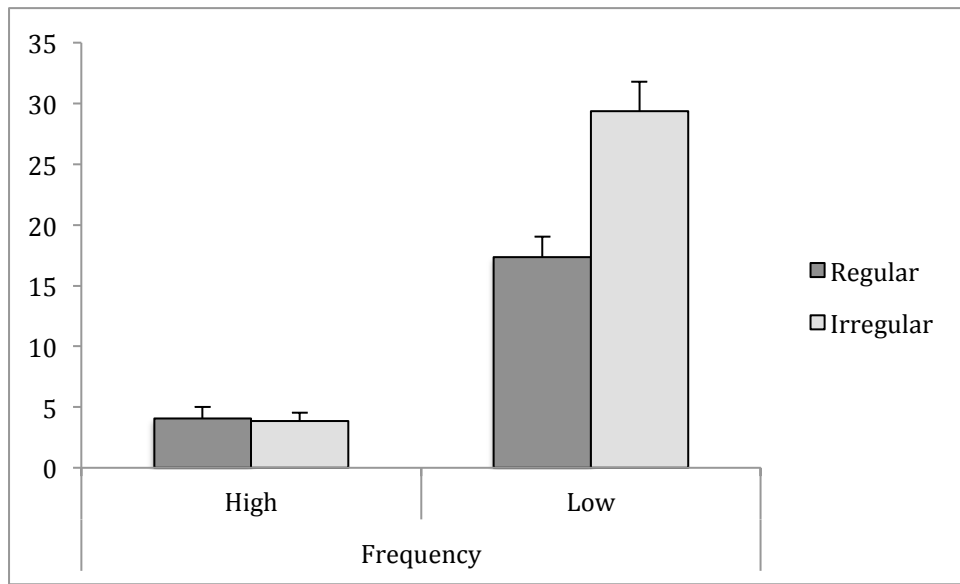
Table 3

Correlations between the Regularity effects for low frequency words, reading level (regular, irregular and nonword reading), age and vocabulary

	1	2	3	4	5	6
1. Regularity effect low frequency words	1					
2. Age	-.01	1				
3. Vocabulary	-.17	.02	1			
4. CC2 regular words accuracy	-.37**	-.09	.29*	1		
5. CC2 irregular words accuracy	-.48**	-.03	.41**	.59**	1	
6. CC2 nonwords accuracy	-.38**	-.08	.36**	.81**	.62**	1

* = $p < .05$. ** $p < .001$, all 2-tailed

Figure 1. Regularity by Frequency interaction for error percentages



Appendix

Stimuli

HF Regular	LF Regular	HF Irreg.	LF Irreg.	Nonwords	PsH
fight	board	bath	ache	boach	burd
fresh	cheap	book	breath	buit	cair
goat	chime	build	calf	canx	durt
horse	desk	cook	calm	desp	ferm
life	doom	eye	cute	doop	flore
mess	globe	ghost	fuel	fisp	foar
miss	grill	gold	gnaw	freve	frese
pond	note	half	halt	glibe	frute
quick	plate	laugh	mild	grigs	gurl
roar	praise	once	mast	mift	hamb
sound	shack	path	thumb	mirk	hawn
swim	spade	salt	tongue	noth	kwick
thing	stem	walk	worse	praint	laire
prince	wheel	wild	wrap	prip	moar
plug	whip	world	yacht	pund	nifes
				queel	roze
				quim	scurt
				roak	sede
				seld	shurt
				smap	smoak
				souche	thurd

Regularity Effect in Lexical Decisions

spass	wair
stom	whing
swate	wird
swick	worne
thulk	wosh
tonzed	wrip
tuet	wurd
tute	wurm
wolts	yauns