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Orthography Influences the Perception and Production of Speech

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Abstract

One intriguing question in language research concerns the extent to which orthographic information impacts on spoken word processing. Previous research has faced a number of methodological difficulties and has not reached a definitive conclusion. Our research addresses these difficulties by capitalizing on recent developments in the area of word learning. Participants were trained to criterion on a set of associations between novel pictures and novel spoken words. Spelling-sound consistent or inconsistent spellings were introduced on the second day, and the influence of these spellings on speech processing was assessed on the third day. Results showed for the first time significant orthographic effects on speech perception and speech production in a situation in which spelling-sound consistency was manipulated with perfect experimental control. Results are discussed in terms of a highly interactive language system in which there is a rapid and automatic flow of activation in both directions between orthographic and phonological representations.

It is often said that spoken language has primacy over written language. Before acquiring skills in reading and writing, most children have expertise in understanding and producing speech. Indeed, while we are born with the propensity to use spoken language, reading is a learned form of expertise. It is not surprising, then, that language subsystems supporting reading are often characterized as being parasitic on those supporting our spoken abilities (e.g. Pinker, 1997). In line with this characterisation, there is a broad consensus that our experience with the sounds of words (phonology) plays a powerful role in learning to read (e.g. Rayner et al., 2001) and in adult visual word processing (e.g. Rastle & Brysbaert, 2006).

The question that has received less attention is whether our experience with the spellings of words (orthography) comes to influence our spoken abilities. Though inconsistent with the primacy model, an increasing body of literature suggests that speech perception may be shaped by information about the printed forms of words, and there is limited research suggesting that the same could be true of speech production. These data have raised the remarkable possibility that information about the printed forms of words is activated rapidly in spoken language tasks, or that phonological representations themselves are altered as a consequence of literacy acquisition (Muneaux & Zieger, 2004). However, research concerning orthographic influences on speech processing has faced a number of substantial methodological difficulties, and as a result has not reached a definitive conclusion.

Orthographic Influences on Speech Perception

The question of whether orthography influences speech perception was addressed initially by Seidenberg and Tannenhaus (1979), who found that participants made faster rhyme judgements for pairs of words that shared their spellings (e.g., toast-roast) as opposed to pairs of words that did not (e.g., toast-ghost). Subsequent studies have corroborated these findings by demonstrating orthographic effects in phoneme monitoring (Dijkstra, Roelofs, & Fieuws, 1995), phoneme counting (Treiman & Cassar, 1997), and phoneme deletion (Castles, Holmes, Neath, & Kinoshita, 2003). However, many argue that these kinds of tasks reflect metalinguistic knowledge, and so it is difficult to conclude that these studies implicate the automatic activation of orthography in speech perception (see Damian & Bowers, 2009a).

Other studies have approached this issue using priming techniques that measure whether the recognition of an auditory target is speeded by the prior presentation of a phonologically-similar prime that overlaps (e.g., message-mess) or does not overlap (e.g., definite-deaf) with the spelling of the target. Jakimik, Cole, and Rudnicky (1985) reported that shared orthography boosted these auditory priming effects, though this study has been criticized for failing to mitigate the possibility of strategic processing. Subsequent research has resulted in some studies showing clear orthographic effects (e.g. Chereau, Gaskell, & Dumay, 2007) and others producing trends that fail to reach significance over items (e.g. Slowiaczek, Soltano, Wieting, & Bishop, 2003; Taft et al., 2008).

The most compelling evidence for orthographic effects on speech perception comes from studies showing slowed auditory recognition of feedback inconsistent words (i.e. words that can be spelled in many different ways; e.g. Ziegler & Ferrand, 1998). However, while many studies using this approach have reported robust orthographic effects (e.g., Pattamadilok et al., 2007; Ziegler, Ferrand, & Montant, 2004; Ziegler, Petrova, & Ferrand, 2008) others have reported trends that fail to reach significance over items (e.g., Perre & Ziegler, 2008; Ventura, Kolinsky, Pattamadilok, & Morais, 2008; Ventura, Morais, Pattamadilok, & Kolinsky, 2004), a situation that may result from the fact that this evidence is necessarily derived from a between-items comparison in which the introduction of confounding variables is always a risk. Further, while this result has been generalized to semantic categorization and gender decision (Peereman, Dufour, & Burt, 2009), it is unclear whether it holds for tasks that do not involve an explicit decision component. The few studies that have investigated orthographic effects in shadowing have reported null effects (e.g., Pattamadilok et al., 2007; Ventura et al., 2004; Ziegler et al., 2004), but some of these studies also failed to uncover the lexical effects that are often observed in this task (e.g, Tyler, 2000).

Orthographic Influences on Speech Production

The issue of whether orthography influences speech production was investigated initially by Lupker (1982), who asked participants to name pictures while ignoring superimposed distracter words. Results showed that pictures were named more quickly when distracters overlapped target pictures in sound and spelling (e.g. picture: plane; distracter: cane) than when they overlapped only in sound (e.g. picture: plane; distracter: brain). However, though this result was replicated by Damian and Bowers (2009b), no orthographic influences were observed when distracters were presented in the auditory modality, suggesting that these effects may emerge only when orthography is relevant to the task (and calling into question the claim that orthographic representations are activated in speech perception). Similar conclusions could be drawn about related work using the form-preparation paradigm (Meyer, 1990). Damian and Bowers (2003) asked participants to memorize word pairs that occurred in homogeneous blocks in which words overlapped in their initial sound and letter (e.g. coffee-camel), in heterogeneous blocks in which there was no overlap between the words (e.g. gypsy-camel), or in inconsistent blocks in which words overlapped in their initial sound but not letter (e.g. kidney-camel). Participants were then required to produce the second item in each pair when cued by the first. Results showed the typical form preparation advantage of faster recall in homogenous blocks than in heterogeneous blocks, though this advantage was absent in the inconsistent blocks suggesting a role for orthography in speech production. However, this result was not replicated in Dutch (Roelofs, 2006) or Chinese (Chen, Chen, & Dell, 2002), and does not arise when participants are required to name blocks of similar-sounding pictures that overlap or do not overlap in their spelling (Alario, Perre, Castel, & Ziegler, 2007).

A New Approach to Investigating Orthographic Influences on Spoken Language

This review demonstrates that methodological difficulties have made it difficult to draw strong conclusions about orthographic influences on speech perception, and that there has been insufficient research to draw any conclusions about orthographic influences on speech production. Our research offers a new approach to this issue by capitalizing on developments in the area of word learning. Recent research has shown that adults can learn novel words in laboratory situations, and that given a period of overnight consolidation (Dumay & Gaskell, 2007), these novel words come to behave like known words in psycholinguistic tasks (Bowers, Davis, & Hanley, 2005; Gaskell & Dumay, 2003; Merkx, Rastle, & Davis, 2011). The beauty of this paradigm for investigating orthographic effects in spoken language lies in the exquisite methodological control that it offers, making it possible to dispense with the between-item designs that have characterised much of the work on speech perception, and instead select a single set of spoken targets whose spelling-sound characteristics can be manipulated across participants.

Participants in our experiment were trained and tested on a set of novel words and pictures over three successive days. On the first day, they were trained on the spoken forms of these novel words together with their pictures, until their performance reached criterion. Spelling-sound consistent or inconsistent orthographic representations of the novel words were introduced on the second day, then on the third day participants were tested on a range of speeded speech perception and production tasks including auditory lexical decision, shadowing, and picture naming. Critically, none of these tasks involved presentation of an orthographic stimulus. Further, in order to ensure that any null effects of orthography were not due to participants' failure to learn the spellings presented to them on the second day, we conducted a picture spelling test and a forced choice spelling test at the end of the third day. Our aims were to discover whether the nature of the orthographic code assigned to the novel spoken words would have any impact on the perception and production of those novel spoken words and to ascertain whether this impact was restricted to certain test tasks.

Method

Participants.

Participants were 12 native monolingual Southern British English speakers from an undergraduate population. None reported dyslexia or other language impairment. Participants were paid £30 for their participation.

Stimuli and Apparatus.

Training stimuli consisted of twenty novel objects pictured as black and white line drawings. Each of these objects was given a novel spoken name whose initial phoneme could be spelled in a regular or irregular manner based on existing English spelling-sound relationships (e.g. /kIsp/ spelled kisp or chisp; see Appendix). Length and orthographic N were matched across regular and irregular spellings of the spoken words (length: regular M=4.35 letters, irregular: M=4.55 letters; N: regular M=3.5 neighbours, irregular M=2.6 neighbours). The assignment of regular or irregular spellings to novel objects was counterbalanced across two versions. The names of the novel objects were recorded by a native speaker of Southern British English.

There were five test tasks implemented over the three days of training and testing. The picture naming task used the twenty line drawings learned in training and required a naming response from participants. The auditory lexical decision task used the spoken forms of the twenty new words learned by participants for the 'yes' response (though these were recorded by a different speaker of Southern British English) and twenty spoken nonwords for the 'no' response. The items used for the 'no' response were matched to learned items on onset, consonant-vowel structure, phonological neighbourhood size, and acoustic duration. The shadowing task used all forty stimuli from the auditory lexical decision task plus an additional twenty untrained nonwords matched to the learned items on the same factors described above. The picture spelling task used the twenty line drawings learned in training and required a spelling response from participants. Finally, the spelling forced choice task used the regular and irregular spellings of each novel object and required participants to decide which they had learned.

Stimulus presentation and data recording were controlled by DMDX software (Forster & Forster, 2003). Responses for the five test tasks were acquired using a button box (auditory lexical decision, spelling forced choice), the keyboard (picture spelling), and a Beyerdynamic headset microphone (picture naming, shadowing).

Procedure.

Participants were trained and tested over three days.

(a) Day 1. Participants were told to learn the spoken names of a set of novel objects, and that their performance would be assessed in a picture naming task. They were told that they had up to two hours to achieve a minimum of 80% accuracy and that failure to achieve this result would mean that they could not progress to the following days and that they would receive only £5. No participants were excluded from the experiment on this basis.

Participants were exposed to the novel spoken words and their pictures in a series of study and verification blocks. During study blocks, participants were shown a novel picture while listening to its name on headphones, and repeated its name after each trial. During verification blocks, participants chose the correct spoken name from either two or three pictures, and were given feedback consisting of the correct picture-word pairing on each trial. Participants were exposed to the correct picture-name pairings six times during study blocks and a further six times as feedback during verification blocks. Following this fixed training period, participants attempted to name all twenty pictures. If performance was not 80% accurate at this stage, they were asked to study a chart of all twenty pictures whose spoken names could be accessed on a mouse click. Participants were retested after revision periods of ten minutes until they reached 80% accuracy in picture naming performance.

(b) Day 2. Participants named all twenty pictures at the beginning of Day 2 prior to the introduction of their spellings. Spellings were then introduced through a series of study and verification blocks that mirrored those used on Day 1. During study blocks, each spelling was presented in conjunction with its picture and spoken name, and participants were required to type the name after each presentation. During verification blocks, participants chose which of two or three pictures was associated with the spelling. Feedback was given on each verification trial that consisted of the picture and its spoken and written name.

Participants named all twenty pictures after this orthographic training period. They then completed a surprise spelling test that assessed learning of the written names.

(c) Day 3. Participants were given the five test tasks in the following order: auditory lexical decision, picture naming, shadowing, picture spelling, and forced choice spelling. In auditory lexical decision, participants decided whether spoken stimuli presented over headphones were words or nonwords; the instructions specified that “words” included any that they had recently learned. In picture naming, participants named the novel pictures learned in training as rapidly as possible. In shadowing, participants repeated trained new words and untrained nonwords as rapidly as possible. In picture spelling, participants wrote the names of the novel pictures learned in training. Finally, in forced choice spelling, participants decided as rapidly as possible which of two spellings they had learned in orthographic training.

Results

Reaction times (RTs) for spoken responses in picture naming and shadowing were derived manually via visual inspection of the speech waveform using CheckVocal software (Protopapas, 2007).

(a) Picture naming. Picture naming was assessed at four time points during the experiment, once at the end of Day 1 when 80% accuracy had been achieved, twice on Day 2 (before and after orthographic training), and once on Day 3. RTs were analyzed by participants and by items using three-factor analyses of variance (ANOVAs). The analysis by participants treated time of testing (four levels) and spelling regularity (two levels) as repeated factors and version (two levels) as an unrepeated factor. The analysis by items treated time of testing and regularity as repeated factors and version as an unrepeated factor. RT and error data by participants are shown in Table 1.

<Table 1 about here>

Critically, the latency analysis revealed a significant interaction between time and regularity, $F_1(3,30)=5.11$, $p<0.01$, $F_2(3,54)=4.65$, $p<0.001$. This interaction reflected the fact that spelling regularity influenced picture naming latency at both time points after orthographic training (Day 2 post orthography training: $t_1(11)=4.06$, $p=0.002$, $t_2(19)=5.60$, $p=0.001$; Day 3 testing: $t_1(11)=2.44$, $p=0.04$, $t_2(19)=2.71$, $p=0.014$), but not prior to the introduction of orthography (Day 1: $t_1(11)=-0.23$, n.s., $t_2(19)=0.65$, n.s.; Day 2 pre-orthography training: $t_1(11)=0.00$, n.s., $t_2(19)=0.35$, n.s.). In the presence of this interaction, main effects on the latency data are not reported. The accuracy analysis revealed a main effect of time of testing since participants' performance improved with increasing exposure to the stimuli, $F_1(3,30)=10.79$, $p<0.001$, $F_2(3,54)=8.02$, $p<0.001$. There were no other main effects or interactions that reached significance both by participants and items.

(b) Auditory lexical decision. RT data for 'yes' responses were analyzed using two-factor ANOVAs. The analysis by participants treated target type (regular or irregular) as a repeated factor and version as an unrepeated factor, while the analysis by items treated both variables as unrepeated. The latency analysis revealed a main effect of regularity (Regular $M=1068$ ms; Irregular $M=1174$ ms:

$F_1(1,10)=10.60$, $p<0.01$, $F_2(1,18)=5.03$, $p<0.05$). There were no effects that reached significance in the accuracy analysis (regular error $M=5.0\%$, irregular error $M=4.2\%$; all ps >0.5).

(c) Shadowing. RT data were analyzed using two-factor ANOVAs that treated target type (regular, irregular, untrained) as a repeated factor by participants and as an unrepeated factor by items, and that treated version as an unrepeated factor both by participants and by items. The latency analysis revealed a main effect of target type, $F_1(1,10)=4.77$, $p<0.05$, $F_2(2,79)=4.96$, $p<0.05$. Follow-up t-tests showed that learned words were produced more quickly than untrained items (learned $M=916$ ms, untrained $M=952$ ms, $t_1(11)=2.67$, $p<0.05$, $t_2(78)=3.17$, $p<0.01$), whereas there was no difference in shadowing latency for regular and irregular items (regular $M=914$ ms, irregular $M=918$ ms, $t_1(11)=0.25$, n.s., $t_2(19)=0.23$, n.s.). Error rates were extremely low (less than 1% for all conditions), and there were no effects that reached significance (all ps>0.5).

(d) Picture spelling. Knowledge of the spellings of the novel words was highly accurate on Day 2 (regular $M=98.3\%$, irregular $M=97.5\%$) and remained so at the end of Day 3 (regular $M=95.8\%$, irregular $M=91.7\%$). There were no significant effects of regularity ($F_1(1,10)=2.6$, n.s., $F_2(1,18)=9.78$, $p=0.01$) or day of testing on picture spelling ($F_1(1,10)=2.57$, n.s., $F_2(1,18)=3.24$, n.s.), and there was no interaction between these factors ($F_1(1,10)=1.29$, n.s.; $F_2(1,18)=1.39$, n.s.).

(e) Forced choice spelling. One participant was removed from this analysis because he was unable to reach a decision within 6 seconds, and three additional data points greater than 3000 ms were removed. Results revealed no effect of regularity on forced choice spelling RT (regular $M=1086$ ms, irregular $M=1108$ ms, $t_1(10)=0.38$, n.s., $t_2(19)=0.99$, n.s.) or accuracy (regular error $M=7.3\%$, irregular error $M=6.4\%$, $t_1(11)=0.29$, n.s., $t_2(19)=0.55$, n.s.).

Discussion

One important question in language processing research concerns the effect of literacy on speech processing. Despite the fact that reading is a learned form of expertise that is critically dependent on our inborn capacity for speech, substantial evidence is suggestive that speech perception may be critically influenced by orthographic representations once literacy is acquired, and there is emerging evidence to this effect in respect of speech production. However, much of this evidence has not been statistically robust, and some of the findings have proven difficult to replicate. Further, it remains unknown the extent to which these findings reflect properties of the tasks used to measure speech processing as opposed to reflecting properties of the speech processing system itself.

Our approach to this issue was to train and test participants on a novel spoken vocabulary over three successive days. On the first day participants were trained to criterion on a set of associations between novel pictures and novel spoken words. Spelling-sound consistent or inconsistent spellings were introduced on the second day in a fully-counterbalanced manner, and we assessed the influence of these spellings on the third day in a series of speech processing tasks, none of which involved orthography. In respect of speech perception, results showed a significant orthographic effect on auditory lexical decision but not on shadowing, thus replicating previous findings with real words (e.g. Pattamadilok et al., 2007; Ziegler et al., 2004). In respect of speech production, results showed for the first time an effect of orthography on simple picture naming that emerged immediately following the introduction of the spellings of words on the second day, and that persisted in testing on the third day. These results demonstrate orthographic involvement in speech processing tasks that do not require orthographic processing, and in a situation in which spelling-sound consistency can be manipulated with perfect experimental control.

How might orthography have influenced these speech processing tasks? One relatively uninteresting possibility is that participants simply didn’t have the resources to learn items in the irregular condition fully, perhaps due to the additional attentional or working memory requirements of learning an unusual spelling-sound mapping. This is unlikely given that (a) participants had already learned the phonology of the novel words to a high criterion prior to the introduction of the orthography; (b) participants learned the regular and irregular spellings equally well; (c) participants showed an equal benefit for stimuli with regular and irregular spellings in shadowing relative to untrained stimuli; and (d) picture naming performance for items with irregular spellings actually improved following the introduction of orthography. More likely is that the effects observed arose because orthographic representations are activated automatically during speech processing. For example, if a picture of a /kIsp/ activates the orthography CHISP, then this orthography may lead to activation of the regular pronunciation /tSIsp/, thus slowing picture naming by virtue of phonological competition between /tS/ and /k/. Similarly, the activation of the orthography CHISP (and subsequent activation of /tSIsp/) on presentation of the auditory stimulus /kIsp/ may interfere with participants' decisions about whether this was a learned item in the auditory lexical decision task.

One aspect of our results that needs to be explained is why orthographic effects do not appear to be found in shadowing (whether in our experiment or in the previous literature). Two kinds of explanation have been proposed previously. One states that orthographic representations might be activated only in spoken tasks that involve a decision component (Ventura et al., 2004). However, the fact that strong orthographic effects were observed in a simple picture naming task in our experiment allows us to discount this explanation. The other explanation that has been proposed is that orthographic representations are activated only when spoken stimuli are represented lexically, and shadowing does not activate lexical representations (Ventura et al., 2004). The problem for this explanation is that the shadowing data in our study showed a strong effect of learning, suggesting that lexical representations of the trained words had been activated. Thus, neither of these accounts appears to offer a satisfactory explanation of the different patterns of effects observed in shadowing as opposed to picture naming and auditory lexical decision.

A third type of explanation that we propose stresses the importance of the relative time course of orthographic and phonological information. When the stimulus is a spoken word or nonword, phonological activation has a head-start over orthographic activation. Thus, when participants hear the new word /kIsp/ they activate their corresponding phonological lexical representation earlier than the orthographic lexical representation (e.g., CHISP). When the task is simply to repeat the spoken stimulus, this phonological activation can drive the process of speech production before there is much opportunity for orthographic feedback to exert an influence, thus explaining the lack of spelling-sound consistency effects in the shadowing task. When the task requires additional processing stages as in auditory lexical decision, the extra time required to perform the task provides greater opportunity for inconsistent orthographic feedback to activate conflicting phonological representations, thus slowing response times (or for consistent orthographic feedback, to reinforce the correct phonological representation, thus speeding response times). Finally, when the task is picture naming, the stimulus simultaneously activates orthographic and phonological representations, so that phonological activation does not have any head-start over orthographic activation. In this situation there is considerable opportunity for orthographic feedback to influence speech production, thus explaining the strong spelling-sound consistency effects we observed. Although this account emphasises the importance of the relative time course of orthographic and phonological information, it should be noted that the current data do not allow us to rule out a related account, in which task difficulty rather than time course is the critical factor. Adjudicating between these two possibilities will be one goal for future research.

Two final points are worthy of consideration. Previous research on the regularity effect in reading aloud has established that this effect interacts with word frequency (e.g. Seidenberg et al., 1984) and position of irregularity (e.g. Rastle & Coltheart, 1999). That is, the regularity effect is smaller for higher-frequency words, and for words in which the irregularity occurs later in the word. On the basis of the regularity by frequency interaction, we might reasonably expect that the regularity effect that we observed would get smaller if participants were given additional training on the new words. It is more difficult to make predictions regarding the effect of position of irregularity, given that both the speech stream and the putative phonological recoding process involve a serial component. Further research will therefore be required to establish whether our result generalizes to the situation in which the irregularity occurs in the coda.

In conclusion, our results provide the clearest evidence to date of orthographic involvement in speech processing. These orthographic effects can best be understood as reflecting massive interactivity in language processing, in which previously learned spelling-sound associations give rise to a rapid and automatic flow of activation in both directions between orthographic and phonological representations. Our results may also provide some clues as to the relative time-course of orthographic and phonological information as a function of the nature of the input stimulus and the task; this aspect of language processing will be an important one for further investigations. Finally, this study provides a further illustration of the methodological advantages offered by novel word training paradigms in psycholinguistics (e.g., Bowers et al., 2005; Gaskell & Dumay, 2003; Merkx et al., 2011).

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Table 1: RT (in ms) and percentage error (in parentheses) as a function of time of testing and spelling regularity of trained written names.

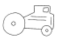
Time of Testing	Regular	Irregular	Difference
Day 1	1235 (9.2)	1255 (6.7)	$20^{n.s.}$
Day 2 Pre-orthographic training	1361 (13.3)	1361 (15.8)	$0^{n.s.}$
Day 2 Post-orthographic training	1052 (2.5)	1270 (5.0)	218^{*}
Day 3	1071 (2.5)	1239 (5.0)	168^{**}

Note: Data for Day 1 and Day 2 Pre-orthographic training reflect picture naming times for groups of items that were later assigned to the irregular and regular conditions. *n.s.* = not significant ($p > .05$), * denotes $p<.05$, ** denotes $p<.005$.

Appendix

Test pictures, spoken names and written names

Picture	Irregular Spelling	Regular Spelling	I.P.A.
	THIMP	TIMP	/tɪmp/
	SURP	SHURP	/ʃɜp/
	CERK	CHERK	/tʃɜk/
	WHOFF	HOFF	/hɒf/
	CHONT	KONT	/kɒnt/
	THESH	TESH	/tɛʃ/
	SULF	SHULF	/ʃʌlf/
	CESK	CHESK	/tʃɛsk/
	WHOAT	HOAT	/həʊt/
	CHISP	KISP	/kɪsp/
	THIST	TIST	/tɪst/
	SUST	SHUST	/ʃʌst/
	CEFT	CHEFT	/tʃɛft/
	WHOBE	HOBE	/həʊb/

	CHIRM	KIRM	/kɜm/
	THUSP	TUSP	/tʌsp/
	SUME	SHUME	/ʃum/
	CELP	CHELP	/tʃɛlp/
	WHOSK	HOSK	/hɒsk/
	CHIBE	KIBE	/kaɪb/