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Developing a universal model of reading necessitates cracking the orthographic code
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Abstract:	I argue, contra Frost, that when prime lexicality and target density are considered it is not clear that there are fundamental differences between form priming effects in Semitic and European languages. Furthermore, identifying and naming printed words in these languages raises common theoretical problems. Solving these problems and developing a universal model of reading necessitates "cracking" the orthographic input code.

1. **Author of Target Article:** Ram Frost

2. **Word counts:** a) Abstract 60 words, b) Main text 999 words, c) References 377 words, d) Entire Text 1535 words.

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10. **Abstract:**

I argue, *contra* Frost, that when prime lexicality and target density are considered it is not clear that there are fundamental differences between form priming effects in Semitic and European languages. Furthermore, identifying and naming printed words in these languages raises common theoretical problems. Solving these problems and developing a universal model of reading necessitates "cracking" the orthographic input code.

11. Main Text:

A surprising claim made by Frost (2012) is that (in Hebrew) "*letter order cannot be flexible but has to be extremely rigid*" (p. 26). The basis for this claim is the observation that different roots often share different orderings of the same three consonants. But of course the same problem arises in English when distinguishing words like *calm* and *clam*. Successful identification of printed words in English and Hebrew requires a combination of exquisite sensitivity to relative position and considerable flexibility with respect to absolute letter position. "Extreme rigidity" might work very well if all of the Hebrew words that shared the same root contained the letters of that root in the same positions, as is the case for the root Z.M.R in *zemer* (song) and *zamir* (nightingale). But Hebrew orthography does not admit such a simple solution, as is illustrated by words like *zimra* (singing, music)*, z'miryah* (music festival)*,* and *kleizemer* (musical instruments). Once again, the same problem arises in English. To appreciate the relationship between *build*, *builder*, *rebuild*, and *shipbuilding* there must be commonality in the orthographic code for the *build* morpheme in these strings. Rigid, position-specific coding (whether left- or right-aligned) cannot accommodate this requirement, because the letters of *build* occur in different positions within these strings. This *alignment problem* (Davis, 1999), was a key motivation for the development of spatial coding, and is the fundamental reason why models of reading must address the issue of orthographic input coding. The alignment problem is common to many different orthographies, and models that attempt to solve this problem are addressing a universal constraint.

Frost's (2012) invocation of a *universality constraint* to critique current models is based chiefly on a consideration of masked form priming effects. His review may give the impression that form priming effects are found without fail in European languages (and virtually never in Semitic languages), but the full story is more complicated. First, masked form primes give rise to inhibition when the prime is itself a word, e.g., the prime *calm* inhibits identification of the target *clam* (Andrews, 1996; see also Davis & Lupker, 2006). This finding is predicted by models like the spatial coding model (Davis, 2010), because the ability to discriminate words like *calm* and *clam* depends both on accurate encoding of letter order *and* lexical inhibition. The latter mechanism ensures that the lexical representation that is most strongly supported by the orthographic input is able to suppress its competitors. By extension, representing root morphemes at the processing level above letters (e.g., Andrews & Davis, 1999; Davis, 1999, pp. 324-353) would lead to the prediction that transpositions that give rise to a different root than that embedded in the target should result in inhibitory priming, which is what Velan and Frost (2009) observed in Hebrew. Second, null form priming effects are found in European languages for words with dense orthographic neighbourhoods (e.g., Forster & Davis, 1991; Perea & Rosa, 2000). Thus, it is not at all clear that either the inhibitory or the null form priming effects that have been reported in Hebrew (a notoriously dense orthography) are inconsistent with findings from European languages. Furthermore, monomorphemic words with sparse neighbourhoods show the same pattern of facilitatory priming effects in Semitic and European languages. There is every reason to think that a successful model of Hebrew word identification could incorporate the same coding and processing mechanisms as the spatial coding model (Davis, 1999, 2010).

The other constraint discussed by Frost (2012) is what he refers to as the *linguistic plausibility constraint*. In criticising the 'new wave' of 'orthographic models' for failing this

constraint, Frost appears to suggest that the spatial coding model is *"structured in a way that goes counter to the established findings for other linguistic dimensions" (p. 11)*. But if so, it's unclear what aspect of the model he is referring to. Elsewhere he criticises the model for focussing exclusively on orthographic processing, but as Davis (2010) notes, this is not intended as a claim regarding the structure of the visual word recognition system, but rather as a commitment to nested modelling (e.g., Jacobs & Grainger, 1994) and what Andrews (2006) has referred to as temporal (as opposed to structural) modularity. That is, like other modellers, I have taken the approach of focussing on specific components of the full problem, but using a modelling framework that has been successful in capturing other aspects of performance, including effects in the Reicher-Wheeler test, speeded naming and lexical decision (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; McClelland & Rumelhart, 1981; Perry, Zorzi, & Ziegler, 2007). The commitment to temporal modularity does not imply *"that an adequate description of the cognitive operations involved in recognizing printed words is constrained solely by the properties of orthographic structure"* (Frost, p. 38), but rather that, for skilled readers, printed words are most often identified principally on the basis of orthographic information, with phonological and semantic information being retrieved later.

Frost (2012) argues that models which learn will provide the ultimate answer to our modelling problems. I am a proponent of such models, but also appreciate the value of using handwired models to better understand what must be learnt. Correlations between orthography and semantics or phonology cannot be discovered by any learning algorithm unless the input is structured in a way that preserves these correlations. Frost (2012) notes that, well before the new wave of models, Seidenberg and McClelland (1989) offered an alternative to position-specific coding. What he doesn't note is that subsequent iterations of

this modelling framework (correctly) blamed this alternative for the failure of this model to satisfactorily learn the mapping from orthography to phonology (Plaut et al., 1996). The need to learn context-invariant mappings from letters to phonemes highlights another aspect of the alignment problem, and another motivation for assuming position-independent letter representations (Davis, 2010). In summary, cracking the orthographic input code is not simply an intellectual puzzle concerned with explaining transposed letter effects – it is a fundamental requirement for developing a general theory of reading.

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