There are numerous reports that two factors can have additive effects on timed performance in various language tasks. Despite 25 years of work, adherents of the dominant theoretical framework for language processing have yet to publicly address even a single instance of such additivity. It is time to do so.

Visual Language Processing and Additive Effects of Multiple Factors on Timed Performance: A Challenge for the Interactive Activation Framework?

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Language processing at the level of the (printed) word (and below as in sub-lexical spelling-sound translation) is among the most active and sophisticated areas of research in cognitive psychology. This is also true of connectionist (both localist and distributed) *modeling* of such processes (e.g., reading aloud, lexical decision, perceptual identification and semantic categorization; McClelland & Rumelhart, 1981; McClelland, 1987; Norris, 2006; Coltheart, Rastle, Perry, Langdon & Zielger, 2001; Seidenberg & McClelland, 1989; Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg & Patterson, 1996; Plaut & Booth, 2000, 2006; Zorzi, Houghton & Butterworth, 1998, among others). Many of these models (but certainly not all)[1] have levels that are engaged in *interactive activation* (IA) following the seminal theoretical and computational work by McClelland and Rumelhart (1981; see also McClelland, 1987). Indeed, judging by citation counts, the contents of numerous refereed journal papers, chapters and books), the interactive-activation framework is *the* dominant framework in language processing.[2] That is, processing is (1) *cascaded* in that as soon as even a small amount of activation occurs at some level it is fed forward to subsequent special purpose modules (e.g., letter level, word level, semantic level), and (2) that ongoing processing at those levels also feeds activation back to the immediately adjacent level.

The purpose of the present note is to (a) revisit a 25-year-old issue that, like the proverbial elephant in the living room, has been largely ignored, and (b) challenge modellers to address it. The issue is this: Despite widespread enthusiasm for the IA framework, especially in the context of timed performance (e.g., reading aloud, lexical decision and semantic categorization) shouldn't cognitive psychologists be asking whether the assumption of IA is consistent with certain findings, or minimally, whether such findings impose constraints on how widespread such processing is?

To put the issue in more concrete terms, there are multiple demonstrations of additivity of factor effects on RT in the visual word-recognition literature with skilled readers (see Table 1 for some examples). Can a computational model produce additive effects of two factors on RT? Certainly, the ability to produce additive effects of two factors on RT when cascaded processing is feed-forward only has been shown to have limitations (Roberts & Sternberg, 1993) though it is certainly possible (at least on mean RTs; Ashby, 1982). Why would an IA framework be more (rather than less) likely to be able to produce additive effects on RT? Most generally, if the challenge to produce additive effects with an IA model is not met,[3] shouldn't our theories change to reflect this? But perhaps we are getting ahead of ourselves. Maybe an IA model can simulate additive effects of two (or more) factors on RT in an easy and general way.[4,5] If it can, then why has the field not seen such a demonstration a quarter of a century following the publication of McClelland and Rumelhart (1981)?

Table 1

Examples of Additivity of Factor Effects on RT in Lexical Decision and Reading Aloud

Lexical Decision	*Lexical decision and Reading Aloud*
1. ***Stimulus quality and word frequency*** Stanners et al (1975) Becker & Killion (1977) Wilding (1988)[6] Borowsky & Besner (1993) Plourde & Besner (1997) Yap & Balota (2006) *2.* ***Stimulus quality and semantic priming (when relatedness proportion is .25)*** Stolz & Neely (1995) Brown & Besner (2006) *3*. ***Stimulus quality and semantic priming (when [spatial] cueing proportion is low)*** Stolz & Stevanovski (2004) *4.* ***Semantic priming and [spatial] cueing (when cue proportion is low)*** Stolz & McCann (2000) Stolz & Stevanovski (2004) 5. ***Spatial cueing and word frequency/ lexicality*** McCann, Folk & Johnston (1992)	*6.* ***SOA and word frequency (in the Psychological Refractory Period [PRP] paradigm)*** McCann, Remington & Van Selst (2000) **Reading aloud** *1.* ***Stimulus quality and neighborhood density (for non-words)*** Reynolds & Besner (2004) *2.* ***Stimulus quality and letter length (for non-words)*** Besner & Roberts (2003)[7] 3. ***SOA and letter length/whammies (for nonwords in the PRP paradigm)*** Reynolds & Besner (2006) *4.* ***SOA and word frequency (in the PRP paradigm)*** McCann et al (2000)

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FOOTNOTES

[1] The *only* computational model of visual word recognition I am aware of that has attempted to simulate additive effects of two factors on RT eschews interactive-activation in favor of cascaded processing that is feed-forward only (Plaut & Booth, 2000; 2006). This attempt is also interesting from another perspective: someone believes sufficiently in at least these additive effects to try and model them.

[2] Sternberg's seminal work (e.g., Sternberg, 1998) is often ignored in the reading literature. Perhaps this is because of the widely held (but unsubstantiated) assumption that language processing is not to be understood in terms of serially organized stages.

[3] Reynolds and Besner (2004) were able to simulate additivity of stimulus quality and word frequency in the context of reading aloud using Coltheart et al's (2001) IA model. However, additivity was seen only when feedback between certain levels was eliminated, and it held over a very small range of conditions.

[4] Whatever the answer to the question raised here (but especially if it turns out to be difficult for an IA model to produce additive effects on RT), some not so incidental questions remain: Why have modelers avoided this issue? And, why has the field at large been so eager to embrace the IA framework? A tentative and partial answer is that (a) the field lacks young and forceful proponents of non IA models, (b) at least some (recent) editors and action editors believe that additive effects of factors on RT are not "real", and hence they actively discourage discussion of theoretical accounts which assume thresholded processing, and (c) brain anatomy and fMRI studies have encouraged many investigators' belief that feed-forward processing is inevitably accompanied by feedback.

[5] Reviews of a previous version of this note (from *Psychonomic Bulletin & Review*) are interesting from a sociological perspective. The editor concluded that simulations should be done that either provide an existence proof or suggest that additivity is difficult to produce. My response to this is to agree: Those who are promulgating the IA framework should provide the existence proof. More generally, we want to ensure that there is room on the field for cognitive psychologists who are not modelers to ask questions.

[6] One of Wilding's experiments (with a long ITI) produced an interaction. Wilding attributed the interaction to the joint effects of the long fore-period and attention, arguing that it had nothing to do with reading related processes. Paap (personal communication) has failed to replicate this interaction.

[7] The human data yielded a non-significant 11 ms interaction (low stimulus quality slows long non-words more than short ones). However, further examination of these data (median split into fast/slow subjects) yielded main effects of group, and a significant 3 way interaction in which slow subject yielded a 32 ms over-additive interaction of stimulus quality and letter length (and a larger length effect than for fast subjects), but fast subjects yielded stronger evidence of additive effects (1 ms departure from additivity). One (post hoc) account is that slow subjects are much less sure of their spelling-sound translation, and are hence inclined to re-compute it more often when letter length is long as compared to when it is short, and particularly so when stimulus quality is low.