 Bilingualism: Language and Cognition 5 (3), 2002, 214–215 DOI: 10.1017/S1366728902263014

How do bilinguals control their use of languages?

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Dijkstra and Van Heuven sketch the BIA+ model for visual word processing in bilinguals. BIA+ differs in a number of respects from its predecessor, BIA, the leading implemented model of bilingual visual word recognition. Notably, BIA+ contains a new processing component that deals with task demands. BIA+ has not been computationally implemented yet and design decisions still need to be taken. In this commentary, I outline a proposal for modeling the control of tasks in BIA+.

The issue of task demands and executive control is clearly an important one. Conversations are driven by willed goals – speakers and writers try to achieve communicative intentions, and listeners and readers try to recover these intentions. Bilinguals have more than one language available for use. Thus, action goals such as addressing an interlocutor in one language need to be protected against the inadvertent use of the other language. As concerns bilingual reading, Dijkstra and Van Heuven argue that word recognition is not controlled – a letter string activates all compatible words regardless of their language. However, activated words may be responded to in multiple ways, for example, they may be read aloud, translated or be subjected to a language or lexical decision. Dijkstra and Van Heuven review evidence suggesting that the values of control parameters like decision thresholds may vary depending on the language and task situation. Clearly, what task to perform and responses to select is under the control of a language user.

Before the cognitive revolution in psychology in the middle of last century, associationist and behaviorist theories accounted for task performance and response selection by postulating associations between stimuli and responses. However, if all responses were determined entirely by stimulus-response associations, readers would not be free to choose which response to make to a letter string, because the strongest association (e.g., oral reading) would control the response. When readers are asked to perform one particular task (e.g., language decision) rather than another (e.g., oral reading), they are able to do it, usually without (much) practice. In some way or another, goals can be set to control responding.

On one prominent view, advocated by Norman and Shallice (1986) for cognition in general and adopted by Green (1998) for the control of languages in bilinguals, executive control is achieved by associatively *biasing* activation levels of responses. Goals are "internal stimuli" that favor certain response types. For example, the implemented models of Cohen, Dunbar and McClelland (1990) and Gilbert and Shallice (2002) achieve goal-directed responding by task nodes connected to response pathways in a lexical network. The task nodes selectively activate one pathway (e.g., for language decision) rather than another (e.g., for oral reading).

On another prominent view, advocated by Anderson (1983) among others and implemented in WEAVER++ (Roelofs, 1992, 1997; Levelt, Roelofs and Meyer, 1999), responding is controlled through *explicit* reference to goals. WEAVER++ combines a lexical network with condition-action production rules that determine what is done with the activated lexical information depending on the task. When a goal is placed in working memory, the attention of the system is focussed on those production rules that include the goal among their conditions. Production rules provide flexibility in responding by allowing tasks to be specified through a combination of response types and variables such as "read the stimulus aloud", "translate the stimulus from language *x* into *y*", "decide whether the stimulus is from language *x*", whereby *x* and *y* can take on the values "Dutch" and "English" in Dutch-English bilinguals.

Elsewhere, I have made a case for goal-referenced control of language use (Roelofs, in press). The control of language use has in its simplest form perhaps been most intensively studied by employing the color-word Stroop task (Stroop, 1935) and analogs of it. The basic variant of the Stroop task asks for naming the ink color of color words. Participants are slower and make more errors in naming the ink color of an incongruent color word (e.g., the word RED in blue ink) than in naming the color of Xs, which shows the influence of executive control: the ink colors are named rather than the color words read at the cost of slower responding and more errors.

It has been shown that WEAVER++ successfully simulates sixteen classic data sets on Stroop, mostly taken from the review by MacLeod (1991), including incongruency, congruency, reverse Stroop, response set, semantic gradient, time course, stimulus, spatial, multiple task, manual, bilingual, training, age, and pathological effects (Roelofs, in press). With only three free parameters taking two values each to accommodate task differences (color naming, picture naming, word reading, manual responding), the model accounts for ninety six percent of the variance of the sixteen studies (two hundred fifty data points). Moreover, WEAVER++ successfully simulates the human brain's blood flow response during Stroop task performance in neuroimaging studies, in particular, the fMRI BOLD response in the anterior cingulate cortex, one of the classic brain areas involved with executive control (Roelofs & Hagoort, 2002). It appears that existing associationist models of control cannot account for critical aspects of the data, whereas WEAVER++ can.

Performing a bilingual color naming Stroop task by bilinguals not only calls for naming the ink color rather than reading the word, but it also requires selecting the response from the target language. For example, when a Dutch-English bilingual has to use English in naming the ink color of the Dutch word ROOD (red) in blue ink, correct responding not only requires preventing the selection of the response "rood" but also requires preventing the selection of the Dutch translation equivalent of the English target response "blue", Dutch "blauw". Stroop interference occurs between the languages of bilinguals (e.g., reading Dutch ROOD interferes with the production of "blue" in response to ROOD in blue ink), but the effect is not as great as that within either one of the languages.

Language-specific responding may be achieved by marking the words in memory for language, as done in BIA and WEAVER++ and proposed for BIA+, and specifying the target language in the production rules for response selection, as done in WEAVER++. Simulations have revealed that WEAVER++ accounts for the finding that interference is greater within than between languages (Roelofs, in press). As Dijkstra and Van Heuven argue for BIA+, critical is how the activated words from the non-target language are *used*. In performing a bilingual Stroop task, the words in the non-target language are not considered for selection but still compete indirectly by activating competitor responses in the target language via their shared meaning (e.g., Dutch "rood" activates English "red", which competes with English "blue" in naming the ink color of the Dutch word ROOD in blue). The indirect competition by words from the non-target language explains why the interference is reduced between compared to within languages.

Stroop interference between languages supports BIA+'s and WEAVER++'s assumption that words of the non-target language are processed up to the semantic level in reading. This assumption agrees with the results of a wide range of chronometric studies on bilingual word recognition, reviewed by Dijkstra and Van Heuven, but it is at odds with a recent electrophysiological and fMRI study by Rodriguez-Fornells, Rotte, Heinze, Nösselt and Münte (2002). In this study, bilingual Spanish-Catalan and monolingual Spanish readers were instructed to press a button when reading words in Spanish and to ignore pseudowords and words in Catalan. The evoked electrical brain potentials of both the bilinguals and the monolinguals were sensitive to the frequency of the words in Spanish but not in Catalan. Furthermore, the brain's blood flow response to Spanish words was greater in the posterior inferior frontal cortex and the planum temporale for the bilinguals than for the monolinguals. These areas have been shown to be involved in phonological processing by previous research. According to Rodriguez-Fornells et al., these results suggest that bilingual readers may prevent activation of the words from the non-target language by selectively accessing the lexicon of the target language through application of language-specific sublexical grapheme-to-phoneme correspondence rules and blocking direct visual lexical access for both languages.

However, if bilingual readers can control reading routes, the simplest way to prevent between-language interference in Stroop color naming would be to block all reading routes. But the Stroop findings suggest that bilingual readers are unable to accomplish this. The absence of an effect on brain potentials and the difference in brain activation between monolinguals and bilinguals does not imply, however, that bilingual word recognition is controlled. The bilingual Stroop findings indicate that between-language effects on the use of activated lexical information are reduced compared to within-language effects. Reduced effects for words from the non-target language may lead to an absence of an effect of non-target language words on brain potentials. Furthermore, the availability of two languages rather than one may lead to more extensive processing before responding in bilinguals compared to monolinguals, which may explain the fMRI data.

To conclude, the burgeoning literature on bilingual word recognition is leading theorists to think more and more about issues of control. In modeling executive control, an associationist approach is not the only way to go, however. In developing the task component of BIA+, goal-referenced control warrants serious consideration.

References

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Cohen, J., Dunbar, K. & McClelland, J. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review*, 97, 332–361.

Gilbert, S. M. & Shallice, T. (2002). Task switching: A PDP model. *Cognitive Psychology*, 44, 297–337.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition*, 1, 67–81.

Levelt, W. J. M., Roelofs, A. & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22, 1–38.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, 109, 163–203.

Norman, D. A. & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. J. Davidson, G. E. Schwarts & D. Shapiro (eds.), *Consciousness and self-regulation: Advances in research and theory* (vol. 4), pp. 1–18. New York: Plenum Press.

Rodriguez-Fornells, A., Rotte, M., Heinze, H.-J., Nösselt, T. & Münte, T. (2002). Brain potential and functional MRI evidence for how to handle two languages with one brain. *Nature*, 415, 1026–1029.

Roelofs, A. (1992). A spreading-activation theory of lemma retrieval in speaking. *Cognition*, 42, 107142.

Roelofs, A. (1997). The WEAVER model of word-form encoding in speech production. *Cognition*, 64, 249–284.

Roelofs, A. (in press). Goal-referenced selection of verbal action: Modeling attentional control in the Stroop task. *Psychological Review*.

Roelofs, A. & Hagoort, P. (2002). Control of language use: Cognitive modeling the hemodynamics of Stroop task performance. *Cognitive Brain Research*, 15, 85–97.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18, 643–662.