Mental control of the bilingual lexico-semantic system*

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This paper aims to foster discussion of the means by which bilinguals control their two language systems. It proposes an inhibitory control (IC) model that embodies the principle that there are multiple levels of control. In the model a language task schema (modulated by a higher level of control) "reactively" inhibits potential competitors for production at the lemma level by virtue of their language tags. The IC model is used to expand the explanation of the effect of category blocking in translation proposed by Kroll and Stewart (1994), and predictions of the model are tested against other data. Its relationship to other proposals and models is considered and future directions proposed.

There has been progress in understanding the nature and organization of processes underlying the performance of specific tasks (e.g., single word production, see Levelt, Roelofs and Meyer, in press), but much less evident is an understanding of how various component processes are linked to perform one task rather than another or to switch between tasks (Monsell, 1996). On hearing a word a person could retrieve its meaning, write it down, repeat it (again and again), free associate to it, count the number of letters or syllables in it, or translate it into another language. Given one task to perform rather than another, how do individuals configure the various modules required and ensure that other tasks are not performed instead?

Typically, experimental research requires individuals to perform just one task (e.g., lexical decision, picture naming), and so this aspect of the potential competition between different tasks afforded by a stimulus goes unrecognized. Bilingual research poses the problem of the competition between tasks and the competition between responses quite directly. To exemplify: consider the task of translating a visually presented word. Is this task not also a kind of Stroop task? Bilinguals have to avoid naming the printed word and, instead, produce a translation equivalent as a response. In other circumstances, such as naming a picture, a bilingual speaker is also potentially faced with the problem of selecting between alternative responses.

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This selection problem might seem to be directly connected to the problem of how words are represented in the minds of bilingual speakers. There are a number of proposals about the nature of the bilingual lexico-semantic system (Votaw, 1992) but these proposals have not always addressed the question of how to achieve a desired output. Ervin and Osgood (1954), for instance, did not specify how individuals acquiring their two languages (L1 and L2) in the same environment and so creating a compound system, in their terms, could ever produce a word in L1 when its meaning can also be expressed by its translation equivalent in L2 (see Green, 1993, for an extended critique). Potter, So, Von Eckhardt and Feldman (1984) contrasted this view of the relationship between corresponding words in two languages (called the concept mediation hypothesis) with another possibility. Following Weinreich (1953), they supposed that bilinguals may construct a direct lexical link from a word in L2 to its translation equivalent in L1. The result of such a system is that access to the meaning of an L2 word or the route to the production of an L2 word is via the representation of its translation equivalent word in L1. If this is so, how do individuals ever manage to avoid producing a word in L1 when they wish to produce its translation equivalent in L2? Potter et al. concluded on the basis of their experimental evidence in favour of the concept mediation hypothesis, but Kroll and colleagues have provided evidence for a more subtle view.

Kroll and Stewart (1994) in their revised hierarchical model proposed that translation equivalents are connected both through concept-mediation and through direct associative links. However, the strengths of these links differ as a function of

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language. But this model also leaves open questions such as how a person translating from one language to another avoids naming the word to be translated.

Bilinguals, of course, do succeed in speaking one language rather than another and they can also code-switch and can, with varying degrees of success, translate between their languages. And, indeed, the field is not without proposals, some very developed (e.g., Dijkstra and van Heuven, 1998), as to how specific tasks may be performed. Recent years have seen a marked shift in the nature of these proposals. Penfield and Roberts (1959) supposed that in order to speak one language rather than another a bilingual must throw the equivalent of a mental switch. Macnamara and Kushnir (1971) further distinguished between an input switch and output switch so that, for example, a person translating from one language (L1) to a second language (L2) could still comprehend the input in L1. The underlying assumption in both cases was that a language system (or subsystem) is either on or off. However, such an assumption did not go unchallenged either theoretically (Paradis, 1981) or empirically. Later empirical work demonstrated that individuals can be influenced by the nature of a non-selected language (i.e., one that is apparently switched off, though see Grosjean, 1997, 1998, for cautions) and so more recent proposals assume that language systems can be at different levels of activation and that in order to speak one language rather than another its activation level must exceed that of the other language (e.g., Paradis, 1984; Grosjean, 1988, 1997, 1998). A comparable view has also been adopted by individuals researching visual word recognition in bilingual speakers (Grainger, 1993; Dijkstra and Van Heuven, 1998).

The purpose of this paper is to stimulate debate and exploration of the mechanisms of language control in bilinguals. The remainder of paper is structured as follows: The first section likens mental control in language processing to the control of action, a thought which leads to the notion that there are, in fact, multiple levels of control. A proposal is described based on this notion and justified by reference to both experimental and neuropsychological data. The second section describes a specific inhibitory control model, the IC model, for the control of language processing in bilinguals. There are three separable aspects of this model: first, one level of control involves language task schemas that compete to control output; second, the locus of word selection is the lemma level in Levelt et al.'s terms and selection involves the use of language tags; third, control at the lemma level is inhibitory and reactive. The third section applies this model to amplify the account of translation proposed by Kroll and Stewart (1994) and to interpret a crucial finding of these researchers. The IC model generates other predictions, some of which can be assessed against existing data in the area of language task switching, Stroop interference and competitor priming. The final two sections of the paper draw parallels with other accounts and consider future directions.

The regulation of the bilingual lexico-semantic system: multiple levels of control

Grosjean (1985a, 1997, in press) argued that bilinguals can be in different language modes: they may speak one language to the exclusion of the other or, in suitable contexts, they may mix their languages. Such regulation requires sensitivity to external input and the capacity for internal direction. The present proposal meets these requirements for both external (bottom-up/exogenous) and internal (top-down/endogenous) control. It is based on an earlier view (Green, 1986, 1993, 1995, 1997) derived from a model of action proposed by Norman and Shallice (1986; see also Shallice, 1988).

A basic presumption is that the regulation of language processes and the control of action have much in common: language is a form of communicative action. In non-verbal actions, for instance, individuals must specify which object is to be the goal or the specific argument of an action such as grasping. In speech, individuals must specify what role within the syntax of an utterance a particular entity will play. This presumption of communality commands support (e.g., Macnamara, Krauthammer and Bolgar, 1968; Paradis, 1980). A further notion is that regulation is achieved through the modification of levels of activation of language networks, or items within those networks, rather than via a simple switch mechanism (see also De Bot and Schreuder, 1993; Grainger and Dijkstra, 1992; Grosjean, 1988; Meuter, 1994; Paradis, 1981).

The Norman and Shallice model posited distinct systems for controlling routine and non-routine behaviour. The system responsible for a routine behaviour such as driving has direct control over behaviour. This system involved a process termed contention scheduling in which schemas (networks detailing action sequences), triggered by perceptual or cognitive cues, compete to control behaviour by altering their levels of activation. Human action can be analyzed at various levels of detail. At a mid-level are well-learned actions such as making breakfast or getting dressed. At this level the question is which sub-action to carry out and this is subject to voluntary control. Deciding to make coffee, for instance,

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will elicit various component schemas such as filling a kettle. Likewise, such a schema will in turn activate other sub-schemas involved in making precise reaching or grasping movements. At a much higher level are schemas for controlling activities such as going to a restaurant (Schank, 1982).

The term schema as used here refers to mental devices or networks that individuals may construct or adapt on the spot in order to achieve a specific task and not simply to structures in long-term memory. Where a task has been previously performed then the relevant schema can be retrieved and adapted from memory. Such existing schemas underlie the automatic performance of certain skills. Where automatic control is insufficient, as in novel tasks, contention scheduling is modulated by a supervisory attentional system (the SAS). As Shallice and Burgess (1996) discuss, SAS must command a variety of processes, including the construction or modification of existing schemas and the monitoring of their performance with respect to task goals.

Simulations of the contention scheduling system (Cooper, Shallice and Farringdon, 1995; Cooper and Shallice, 1997) based on an interactive activation network (McClelland and Rumelhart, 1981) have shown that when the system is "lesioned" it produces outcomes reminiscent of the behaviour of certain frontal lobe patients, where the mere sight of an object may trigger actions that use it (e.g., Lhermitte, 1983). Such a result provides indirect computational support for the role of the SAS in modulating the activity of task schemas. Slips of action in everyday life are also consistent with the modulatory role of SAS, since these can occur when a person is distracted (Reason, 1984).

The present proposal draws a parallel between experimental tasks such as word translation and lexical decision and schemas at an intermediate level of action. Detailed specification of the actions required to name a word (i.e., the articulation of a word form) are the province of low-level schemas. Schemas for business meetings, letter writing, and conversational exchanges are higher-level schemas.

Evidence for the role of frontal lobes in regulating language tasks in unilingual speakers comes from the poorer performance of frontal lobe patients on Stroop tests (Perret, 1974), and from their poorer performance on sentence completion tasks, especially ones that require them to inhibit prepotent responses (Burgess and Shallice, 1996). Figure 1 depicts the proposal. A conceptualiser (C) builds conceptual representations (based on information in long-term memory), driven by a goal (G) to achieve some effect through language. This communicative and planning intention is mediated by the SAS together with

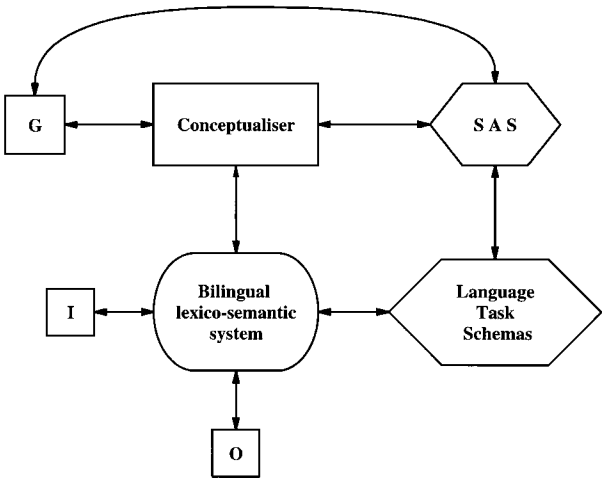


Figure 1. The regulation of the bilingual lexico-semantic system displaying multiple levels of control.

components of the language system, viz: the lexico-semantic system and a set of language task schemas. Language task schemas (e.g., translation schemas or word production schemas) compete to control output from the lexico-semantic system. Willful selection of a word for production requires specification of the required language to be transmitted by SAS to the task schemas. It also requires conceptual information to be transmitted to the lexico-semantic system from the conceptualiser.

Once specified, a schema can be retrieved from memory and, if necessary, adapted to the demands of the task. In order for a schema to regulate behaviour, individuals must maintain the task as a goal. Otherwise, other schemas elicited by the stimulus may produce task-irrelevant behaviour.

A language task schema regulates the outputs from the lexico-semantic system by altering the activation levels of representations within that system and by inhibiting outputs from the system. It remains active until either (1) its goal is achieved, in which case it inhibits its own activity, or (2) it is actively inhibited by another schema, or (3) SAS has changed the goal. SAS achieves a goal only indirectly then by altering the activation levels of a selected schema. It also acts indirectly to configure existing schemas or to construct a schema to perform novel tasks such as lexical decision. In the case of repeated tasks such as the translation of a series of words, the overall task goal maintains the activity of the schema but once a particular word is translated (for instance), it must not be repeated endlessly, unless that is the task goal. So, task schemas must be specified so as to produce a word on input, output its translation and reset themselves.

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An inhibitory control (IC) model

The first part of this section proposes that language task schemas are separable and can be organized into "functional control circuits". The second part overviews the structure of the lexico-semantic system and describes the locus of word selection based on Levelt et al. (in press) and the concept of a language tag. The third part proposes a selection mechanism based on inhibition.

Functional control circuits

Since a given stimulus can evoke different actions on the part of a speaker, different tasks are potentially in competition to control output. In some cases such task-irrelevant schemas appear to be automatically elicited by the stimulus. So, for instance, when individuals are asked to name the hue in which a symbol string is written, the more word-like the symbol string the greater the interference with colour naming (see Monsell, 1996), suggesting that a reading task schema may be elicited by inputs similar to those that normally trigger it. In consequence, part of the basis of Stroop interference may derive from competition between task schemas. Additional interference arises, of course, if the letter string is an incongruent colour word (Stroop, 1935).

Evidence in favour of competitive processes between tasks also derives from experimental studies of task-switching. Rogers and Monsell (1995) required individuals to switch between a task of deciding whether or not a displayed numeral is odd or even to a task of deciding whether or not a displayed letter is a consonant or a vowel. Each trial comprised a display of two characters only one of which was a letter or a digit. Trials of one type alternated with trials of another type in an alternating runs paradigm (e.g., digit task, digit task, letter task, letter task etc.) yielding both switch and non-switch trials. An external cue provided participants with the means to keep track of the task required. Rogers and Monsell showed that a cost in switching between tasks existed even when the time interval between trials involving a task switch was much greater than the time needed to complete the task switch. The switch cost cannot then solely reflect the duration of an internal (top-down) control operation (cf. Meiran, 1996). In addition, they showed that a reduction in cost only occurred when the interval between task switches was both sufficiently long and predictable. The reduction in time cannot therefore reflect the passive decay of an active schema since this should occur even when this interval is unpredictable (cf. Allport, Styles and Hsieh, 1994). There must be a process of active suppression which is initiated when individuals know that the interval is predictable.

Neuropsychological case reports also provide evidence for the separation, competition and coordination of language task schemas. There are bilingual aphasics with a tendency to translate what they produce (e.g., Perecman, 1984; Lebrun, 1991), suggesting that such activity may normally be held in check. However, only knowledge of language performance before brain-damage can really indicate whether or not such behaviour reflects a deficit or a communicative device normally used with bilingual addressees (see Grosjean, 1985b). Most intriguing are cases of paradoxical translation in which a person can translate into a language that they cannot use spontaneously but cannot translate into the language that they can use spontaneously. Paradis, Goldblum and Abidi (1982) described two bilingual aphasic patients who showed paradoxical translation, combined with alternate antagonism (i.e., speaking just one of their two language spontaneously on one day but being unable to speak it spontaneously the next day, instead being able to speak the language that they could not use spontaneously the day before). Consider the case of A.D. On day 18 after a moped accident, A.D. could speak Arabic (call this L1) but could not translate into it. In contrast, she could translate into French (call this L2) even though her spontaneous use of French was poor. The following day she showed the converse pattern: she could speak L2 but not translate into it whereas she could translate into L1 but could not speak it. Comprehension in L1 and L2 was good.

Such a pattern of recovery indicates that speaking a language spontaneously and translating a language are functionally distinct activities. The pattern is also consistent with a problem in controlling a relatively intact lexico-semantic system since destruction of the functional subsystems underlying behaviour cannot yield such transient changes in performance. Consider the pattern of performance on day 18. Minimally, it suggests a functional control circuit in which a translation schema (L1→L2) can call and boost the activity of a word production schema (i.e., that for L2) which can then suppress outputs in L1 and so permit translation into a language which cannot be used spontaneously. However, the fact that A.D. could not translate into a language (L1) that she could use spontaneously suggests that a translation schema cannot always capture the relevant word production schema. Conceivably this is because on the day in question, the L2→L1 translation schema could not dominate the other currently active (L1→L2) trans-

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lation schema, though we will not pursue this speculation.[1] In order for language schemas to exert control over the lexico-semantic system there must be a locus for word selection, a means by which to select and a mechanism of selection.

The locus and means of selection

We have already proposed a conceptualiser that is independent of language. We will not address the question of the mapping of thought into language here but will follow Levelt (1989; and, in particular, Levelt et al., in press) in supposing that each lexical concept is associated with a lemma that specifies its syntactic properties, vital for its use in sentences. The selection of a lemma in production leads to the activation of an associated word form. In the Levelt et al. model the input representation of word forms is distinguished from their output representations but it is assumed that a lemma for a lexical concept such as "chair" is activated in both perception and production.

In order to produce a word in a specific language the intention to do so must be part of the conceptual representation and this conceptual representation must contact the relevant lemmas. We suppose that lemmas are specified in terms of a language tag (see Albert and Obler, 1978, for earlier usage; see also Green, 1986, 1993; Monsell, Matthews and Miller, 1992) and that tag specification is also part of the conceptual representation. Each lemma has an associated tag either for L1 or for L2 and tag specification is one factor affecting the activation of a lemma: it is a condition shared with all other lemmas in the language. A further motivation for believing that the locus of selection is the lemma level is that translation equivalents can differ in their syntactic properties such as gender (der Mond vs. la lune) and such information (e.g., about "moon") is only available at the lemma level (Jescheniak and Levelt, 1994).

The mechanisms of selection

Given a specific language task, such as producing a word in L1, how does the system establish that the right lemma is associated with the right lexical concept? This binding problem may be solved by seeking to ensure that the intended lexical item is the most active at the critical moment (e.g., Dell et al., 1993). Alternatively, as Roelofs (1992) and Levelt et al. (in press) suppose, it may be solved by using a checking procedure that establishes whether or not a lemma node when activated is linked to the appropriate active lexical concept node. Levelt et al. note that this binding-by-checking solution explains why it is that individuals when naming a picture and simultaneously hearing a distractor word rarely produce either semantic errors or phonological errors such as blends of the picture name and the distractor word. We adopt this proposal for present purposes though we note that under certain circumstances such as speeded picture naming (e.g., Vitkovitch, Humphreys and Lloyd-Jones, 1993) individuals may substitute the names of semantically related pictures named 1–15 minutes earlier. This result shows that responses can be triggered by incomplete conceptual matching and indicates that further refinement of this procedure is needed.

But is this the only checking procedure we need? We follow Jescheniak and Levelt (1994) in supposing, at least in the case of an L2 lemma (e.g., the lemma for "chaise" for a native English speaker), that it will point to the L1 lemma for the translation equivalent ("chair"). It follows that in this case there is a checking procedure that establishes that an activated L1 lemma is linked to an active L2 lemma.

Given that a language tag is just one feature, how do we ensure that the correct response controls speech output? The IC model supposes that this is ensured ultimately by suppressing lemmas with incorrect tags. This process of inhibitory control through tag suppression occurs after lemmas linked to active concepts have been activated. It is perfectly possible for a lexical concept in L2 to activate a lemma in L1 to the extent that it shares properties with a concept

[1] Could the pattern of performance reflect variations in the strength of the pathways connecting the various modules in the system? Consider task performance on day 18. Good comprehension with poor production in L1 could reflect a temporary decrease in the strength of the output connection between lexical concepts and lemmas (or between lemmas and word forms). Given such a weakening, translation into L1 might be possible because of activation spreading from the L2 lemma to the L1 lemma and so boosting the output pathway for L1 word forms. Can we explain why A.D. could not translate into the language (L2) that she could use spontaneously? Words in L1 are understood, so there is access to lexical concepts. And since A.D. could speak L2 spontaneously, output connections from lexical concepts to lemmas and so to word forms in L2 are intact. A representational account seems to provide no ready explanation here since there is an intact set of pathways to allow word production. One remaining possibility is that the performance of this pathway is disrupted. Suppose there are also lemma-links between L1 and L2. If the pathway connecting L1 and L2 lemmas is disrupted then it is possible that it could block the selection of the correct L2 lemma even though the mapping between the lexical concept and the relevant L2 lemma is intact. The extent to which this account is really different from a cognitive control account depends on the locus of this interference. If it is a consequence of the failure to suppress the L1 lemma then cognitive control remains a viable account. The advantage of the control account is that it provides an account of why there might be problems.

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in L1. Even the correspondence between so-called translation equivalents may be partial. As Paradis (1997) notes, the English word "ball" and the French word "balle" are not co-extensive (see also De Groot, 1992). In addition, and this was one motivation for the proposal, if there is a route for translation which is not via lexical concepts, then in order for an activated L2 lemma to excite its associated L1 lemma, it must remain active until it has done so and until the checking procedure is completed. Of course at this point it must be inhibited or else it may capture speech production. Inhibition is assumed to be reactive though previous episodes of suppression may exert their effects, since it takes time for the effects of prior inhibition to be overcome.

In short, the IC model supposes that the intention to perform a specific language task is expressed by means of the SAS affecting the activation of language task schemas that themselves compete to control output. These schemas coordinate into "functional circuits" and exert control by activating and inhibiting tags at the lemma level. According to the model, a language task schema can be readied in advance, but because the mechanism of inhibition is reactive, the activation of specific lemmas requires input either from external source (hearing words or reading them) or from the conceptual system. The next section considers a specific application of the model to the findings of Kroll and Stewart (1994) and proposes a number of predictions that are tested against existing data.

The IC model applications and tests

Amplifying the revised hierarchical model

Kroll and Stewart (1994) distinguished independent levels of representation for word form and meaning. There are lexical connections between words that are translation equivalents, and separate connections between each of these words and the representation of their meaning. Figure 2 presents their model; the relative size of the box indicates size of vocabulary. In terms of the connections between word forms, there is a weak link from L1 (the person's native language) to L2 (the person's second language) but a strong link from L2 to L1. In addition, the connections between L2 word forms and meaning are weaker than those between L1 word forms and meaning.[2,3] Arguably, it is which language is currently dominant that is decisive in terms of the relative strengths of these different paths (see Heredia, 1997). For most bilinguals what is their native language and what is their dominant language will coincide but this will not invariably be the case.

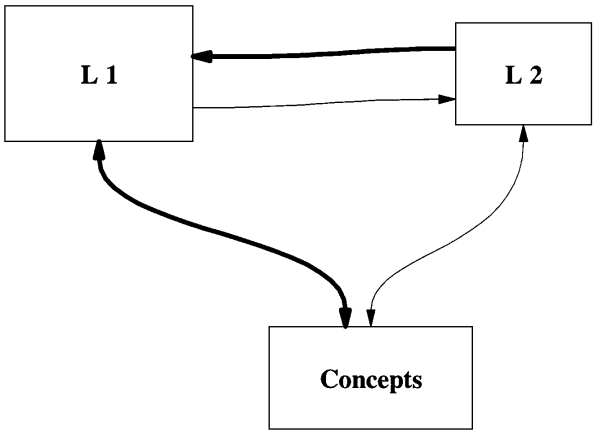


Figure 2. The revised hierarchical model of Kroll and Stewart, 1994.

By way of justification of the model, consider the case in which L2 words are acquired by learning their translation equivalents in L1. A native English speaker learns the French word "maison" by pairing it with its English translation equivalent "house". A word-form to word-form link by itself does not capture the state of the system as the person acquires the meaning of this L2 word. The meaning of a word in L2 is not the word form <house> but its meaning: [man-made] living space. The semantic representation of the word in L1 must therefore be activated at the same time (cf. Keatley, Spinks and De Gelder, 1994). The model captures this differential access to meaning and suggests that even relatively fluent bilinguals may continue to show an asymmetry in accessing meaning in their two languages. However, some reformulation is needed in order for the representation to be compatible with the demands of

[2] The representation of the model is incomplete in the sense that input representations of word forms need to be distinguished from their output representation (see, for example, Morton, 1996; Levelt et al., in press). However, although this issue profoundly affects the predictions that can be made in the tasks used by Potter et al. (1984; see Green, 1997), it does not directly affect the argument here, since it is supposed that the word association hypothesis is consistent with mediation at the lemma level.

[3] Monsell (e.g., 1987) contrasted declarative accounts of the representations of words in the mental lexicon which suppose that words are mentally represented independent of the operations to which they contribute, with a procedural account which supposes that words may not be represented separately from what is done to them. Monsell comments that he is aware of no data that could distinguish these alternatives but the contrast cautions against simply assuming that any task requiring auditory word identification, for instance, necessarily activates the same subsystem.

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speech production. Indeed, Kroll and De Groot (1997, pp. 189–93) have begun to address this point. As above then, we will follow Jescheniak and Levelt (1994, p. 836) in supposing that word-association links involve links between lemmas that are perhaps in addition to, rather than instead of, direct links between word forms.

The revised hierarchical model has generated much productive research (see De Groot, 1995; Kroll and De Groot, 1997 for comprehensive reviews). Converging evidence is consistent with the view that the semantic route is more heavily involved in translating words into L2 from L1 at least in single word contexts (e.g., De Groot and Comijs, 1995) though recent research (see Kroll and De Groot, 1997) also points to a range of factors that moderate this conclusion. Precisely what weight is attached to the semantic route may be a product of the experimental context (e.g., presentation of pictures as in la Heij, Hooglander, Kerling and van der Velden, 1996) and/or the product of acquisition history (see Kroll and De Groot, 1997; MacWhinney, 1997). We concentrate here on the most direct test of the model.

On a strong version of the revised hierarchical model, translating a single word from L1→L2 (forward translation) is achieved through conceptual mediation. It should therefore be affected by semantic factors. In contrast, translating a word from L2→L1 (backward translation) is achieved by non-conceptual links between the word forms (via lemmas) and so should not be so affected. In a test of this prediction, Kroll and Stewart (1994) asked individuals to translate words that were either blocked by category or were randomly selected from various categories. For forward translation, but not for backward translation, individuals took longer to translate words when they were blocked by category compared with when they were presented in a randomised order. In forward translation, blocking words by category leads to "conceptual activation in a specific semantic field" and "creates difficulty in selecting a single lexical entry for production" (Kroll and Stewart, 1994, 168), i.e. there is an increase in the time needed to resolve competition among activated lemmas in L2.

A critical control issue is apparent: how does a person avoid naming the target word in L1 when translating from L1→L2 or avoid naming the target word in L2 when translating from L2→L1? No mechanism is provided. Yet one other possible reason why there is an effect of category blocking in forward translation is that individuals have difficulty regulating the competition amongst lemmas in L1 that become activated via the semantic route just as they do when they are naming category-blocked pictures in L1. In backward translation, the connections between L2 lemmas and meaning are weaker and competition is more readily suppressed. Hence the absence of any effect of category blocking in backward translation.

Given Kroll and Stewart's interpretation of their data (Kroll and Stewart, 1994), their model must be amplified in order to specify how the lexico-semantic system is controlled. Let us consider how this might be achieved. Consider L1→L2 translation. One requirement is to avoid naming the word to be translated. An input word form in L1 must access its lexical concept via its associated lemma. Since the L1 lemmas are active, they will enter the competition for lemma selection for the production of words in L2. However, the competition for the selection can be weighted against L1 lemmas. According to the IC model, at the start of a block of trials, the L1→L2 translation schema calls the production schema for L2. At the stage of selection for output, this schema actively suppresses those lemmas with an L1 tag. Competition then on trial N+1 is primarily among activated L2 lemmas since any L1 lemmas active on the previous trial (N) have been inhibited. In contrast, L2 lemmas active on trial N remain at a relatively high level of activation on trial N+1 since their tags match those of the schema. In consequence, they enter the competition for selection on trial N+1. In the case of translation from L2→L1, given that this is mediated via an L2→L1 lemma link, an L2 lemma transmits activation to its associated L1 lemma. Once again the process of lexical selection must be biased against lemmas with an inappropriate tag. Here, this is achieved by the production schema in L1 that reactively inhibits any activated lemma with an L2 tag. Hence, on this argument the two translation schemas involve the same mechanism of control and a comparable locus of inhibition. The actual outcome of the experiment reflects the relative strength of the connections in the lexico-semantic system just as the Kroll and Stewart model claims.

Predictions and tests of the IC model

Language switching may take time (1) because it involves a change in language schema for a given task, and (2) because any change of language involves overcoming the inhibition of the previous language tags. I know of no direct tests of the costs of switching between different language tasks such as naming and translation, but the IC model predicts that there will be such costs. However, there have been studies of language switching on specific tasks (both receptive and productive) and these confirm that such costs do exist. Of course, in normal speech

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situations that permit prior planning of an utterance, intentional code-switching can be fluent and smooth (see Grosjean and Miller, 1994).

Language switching in reception Consider a lexical decision task in which bilinguals have to decide whether or not a presented letter string is a word in L1 or a word in L2 using the alternating runs paradigm, that is, there is predictable switching between languages. We will describe the study by Von Studnitz and Green (1997; see also Thomas and Allport, 1995) in which the participants were German-English bilingual speakers. The presence of an external cue (the colour of the background on which the letter string is presented) informed participants of the required language for decision. Figure 3 portrays the relationship between this cue and two lexical decision schemas in reciprocal inhibition, and the bilingual lexico-semantic system.

These schemas are established by SAS and relate an output of the bilingual lexico-semantic system (e.g., L1 tag present) to a response (press right key if L1 word). Once established, this control device is driven bottom-up though its performance is monitored by SAS to ensure appropriate performance. In order to respond on a switch trial, the new schema must be triggered by the external cue and suppress the previously active schema. In addition, an input in a different language must overcome the inhibition on its language tags occasioned by the previous trial. In other words, two loci of inhibition are supposed: schema level inhibition and tag inhibition in the bilingual lexico-semantic system. Inhibiting a previously active schema and overcoming the inhibition of the previously irrelevant language will take time and so a switch cost is predicted. For present purposes, we assume that responding to a word in a particular language requires activation of its associated lemma and tag. But we note, as Grainger and Jacobs (1996) suppose, that lexical decision can be based on read-outs from different parts of the system (including word forms, and meaning). We also note (and there is evidence within the study for this claim), that stimuli contact representations in both languages regardless of the target language on that trial (see Smith, 1997, for a review of the evidence on non-selective access in visual word recognition including the role of language-specific cues; Grosjean, 1988, 1997 for relevant research in speech perception). In the case of a non-word response, absence of such a signal by some deadline triggers a "no" response.

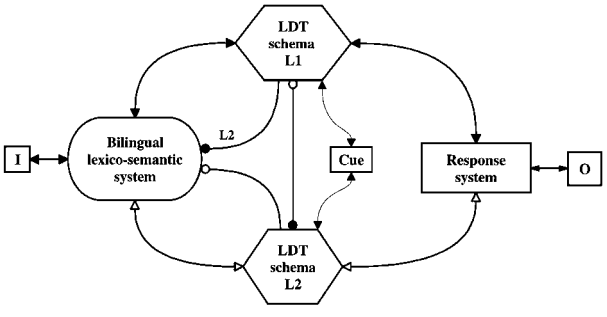


Figure 3. Regulatory processing in a lexical decision task involving language switching (self-inhibitory links on schemas are not depicted). The L1 task schema is shown to be suppressing the L2 task schema and inhibiting L2 lemmas in the bilingual lexico-semantic system.

Von Studnitz and Green (1997, Experiment 1) found an average switch cost of 118 ms (see Grainger and Beauvillain, 1987 for switching costs in a different design). A second experiment examined the effect of language switching when individuals were simply required to decide whether or not the letter string is a word or not. In this case, only one lexical decision schema is needed and this can trigger a response as soon as any language tag becomes active. Accordingly, any switch cost will primarily reflect effects within the bilingual lexico-semantic system itself. A significant switch cost was still obtained (averaging just 17 ms overall) but one that was markedly less than that obtained for the specific lexical decision task.

Language switching in production The IC model also predicts a cost in switching between languages in certain word production tasks such as numeral naming: different language schemas are involved and in order to achieve output, the new schema must dominate the previous one. There will also be a cost in overcoming inhibition within the system. Since both languages are potentially active and competing to control output, successful selection requires the inhibition of active lemmas with non-target tags. Also because inhibition is reactive more active lemmas will be more inhibited. Because overcoming prior inhibition will be a function of the prior amount of suppression, it can be predicted that the cost of switching will be asymmetric. It will take longer to switch into a language which was more suppressed – for unbalanced bilinguals this will be L1, their dominant language.

Meuter (1994; also Meuter and Allport, 1997) examined switching costs in a numeral naming task in which the required language of response was signalled by a colour-background and each trial comprised the presentation of one single-digit number. She found that switching language did yield a switching cost. She also obtained the predicted asymmetry: individuals took longer to switch into their dominant language.

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Unpredictable switching should on average induce greater costs compared with predictable switching, because in the unpredictable case correct performance may sometimes require the intervention of SAS as individuals temporarily overlook the language cue. Trial-by-trial data are not available for this contrast, but Macnamara, Krauthammer and Bolgar (1968) found that estimated average switch costs in numeral naming were less for regular predictable alternations compared to unpredictable ones (210 ms per switch compared to 390 ms per switch, respectively).

What might be predicted under conditions where there are constraints on SAS? Given that schema level activity is monitored by SAS we should expect impaired performance when there is damage to the frontal lobes. Given language asymmetry, frontal lobe damage should induce incorrect switches into L1 from L2 and the occasional failure to switch on cue, especially from L1 into L2. In a pioneering study, Meuter and Humphreys (1997) report the case of an English-Urdu bilingual (FK) who showed this pattern of errors on Meuter's numeral naming task.

Stroop interference The IC model supposes that individuals can establish language tasks and the relationship between them in advance. In principle, then we should find effects of knowing the nature of the interfering stimuli in a Stroop colour naming task. The data of Tzelgov, Henik and Leiser (1990, Experiment 1) support this possibility: the Stroop effect was smaller in the expected language condition for those proficient in the language, suggesting that such individuals were able to control their reading of the colour words. The IC model locates this increase in control at the level of language task schemas: in the expected condition individuals can suppress the word reading schema in their L1 (i.e., more speedily inhibit lemmas activated from that source).

In a unilingual study, Tzelgov, Henik and Berger (1992) showed that reaction times to incongruent Stroop stimuli were faster when participants expected a high proportion of such trials compared with neutral or congruent trials. However, congruent trials showed equal facilitation. According to the IC model, the colour naming schema dominates the word reading schema when individuals know that there is a high proportion of incongruent trials. The effect of the relative dominance of the colour naming schema is that a check of an activated lemma and the lexical concept for the hue is prioritised and so can elicit inhibition of a competing alternative more rapidly and so yield faster response. In the case of congruent stimuli the same lexical concept and lemma is activated and so prioritisation exerts no effect since there is no direct competitor: hence, there is no effect of expectancy on congruent trials.

Cross-language competitor priming Where individuals are consistently translating from one direction to another then the controlling schema is in place and can indirectly (via the word production schema in the target language) reactively inhibit competitors in the non-target language. However, if there is a change of language then any lemmas in the previously active language will become inhibited. In certain circumstances, this should lead to the abolition of both cross-language and within-language competitor priming.

Wheeldon and Monsell (1994) showed that a word produced in response to a priming definition such as "falls in large white flakes from the sky" (snow) interfered with the naming of a subsequently presented probe picture that was semantically related to the concept evoked by the definition (rain). Such competitor interference should also exist across-languages: saying "snow" in response to a definition in English should interfere with naming a semantically related probe picture in French (pluie). However, it will not do so, according to the IC model, if a switch of language intervenes before the probe trial and suppresses lemmas with English tags. Such a switch should also abolish within-language competitor interference.

Lee (1997, Experiment 1) showed just such effects for a group of English-French bilingual speakers. Responses to the critical definitions were in English, but probe pictures were named either in English or in French as stipulated 1300 ms in advance by a language cue. Within-language competitor interference averaged 68 ms and cross-language competitor interference averaged 85 ms. Both kinds of interference were eliminated when there was a change of language before the probe trial. For instance, cross-language competitor interference was eliminated when an intervening trial required individuals to name a semantically unrelated picture in French – a language different from that of the (prime) definition trial. According to the IC model, switching to French suppressed currently active English lemmas and so eliminated, in advance, from the competition for selection in naming the probe picture in French, the English lemma associated with the lexical concept evoked by the definition.

This section has proposed and examined a number of predictions from the IC model. A critical feature is that a dominant language will play an active role in determining reaction time and that selection of an appropriate response will reflect the state of activation of competitors. The claim that control is exerted

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through task schemas is a claim about how intention is expressed and how attention is achieved. A number of questions have been left open and additional predictions from the model will be discussed in the final section. The next section considers the relationship of the IC model to other proposals.

The relationship of the inhibitory control model to other models and proposals on the mechanisms of control

The IC model shares features in common with other accounts of the control of the bilingual lexico-semantic system. The distinction in the IC model between a non-linguistic conceptual system and the system of lexical concepts and word forms relates directly to the three-store model of Paradis (1980, 1997). In addition, the model assumes that the two or more languages of an individual are subsets of the language system as a whole (Paradis, 1989) and this notion is shared by models for both speech perception (Grosjean, 1997), visual word recognition (Dijkstra and van Heuven, 1998) and speech production (de Bot and Schreuder, 1993; Poulisse and Bongaerts, 1994).

All current accounts suppose regulation by activation, though details and mechanisms vary. Paradis (1984, 1997) articulated the basic form of this conjecture in terms of the activation threshold hypothesis. The intention to speak one language rather than another leads to the raising of the activation threshold of the other language system but not to its total inhibition. Conversely, speaking one language reduces the activation threshold of components in the system. Activating and deactivating language systems allows bilinguals to achieve different language modes (Grosjean, 1985a, 1997). In the unilingual (monolingual) mode, one language is the base language and the other is deactivated at least partially. In contrast, in the bilingual mode, when individuals are speaking with others with whom they can code-switch or mix languages, bilinguals adopt one language as the base or matrix language and bring in the other language when required as a "guest" language. In consequence, both languages are relatively active but the base language is more strongly activated. On the IC model, code-switching would involve a co-operative rather than a competitive relationship between the word production schemas.

Models aimed at accounting for speech production in bilinguals adopt the production model of Levelt (1989; Levelt et al., in press) and suppose that lexical selection is achieved through competition between lemmas. In contrast to the IC model and to the proposals of Paradis (1984, 1997), models based directly on Levelt's production model (De Bot and Schreuder, 1993; Poulisse and Bongaerts, 1994; see also Poulisse, 1997) assume no inhibitory mechanisms but rely instead on the notion that the state of activation in non-target lemmas affects the latency to select the target lemma according to a mathematical rule.

Production models differ in the locus of selection. De Bot and Schreuder (1993) presume that the selection of words in a given language is achieved by specifying a language cue which can activate one subset and de-activate another subset. Similar to the IC model, Poulisse and Bongaerts (1994) adopt the notion that lemmas are tagged with a language label and that it is the activation of this tag together with the conceptual information that leads to the selection of a given lemma. Intentional use of L1 during L2 speech, for instance, reflects the increased activation of an L1 lemma and its associated lexical concept. Grosjean (1997) develops the point that in the case of code-switching, both topic and the addressee affect the activation of the guest language. The selection of a relevant lemma is also determined by the conceptual and pragmatic content to be expressed (see also Myers-Scotton and Jake, 1995). In such circumstances where code-switching is not an option, the problem of lexical selection is compounded and such a constraint does indeed induce more hesitation pauses and dysfluencies.

All current proposals, including the IC model, assume that the state of activation of input word forms is a function, in part, of external input. Grosjean and colleagues (see Grosjean, 1997, for a synopsis) have established for the perception of mixed speech some of the relevant factors and constructed a computational model. For instance, increased code-switching prior to a target guest word speeds a target word's recognition. Words marked phonotactically as belonging to the guest language are recognized more readily than those that are not (a phenomenon also shown in visual lexical decision tasks, Grainger and Beauvillain, 1987). BIMOLA (**B**ilingual **M**odel of **L**exical **A**ccess) can account for these effects in terms of the bottom-up flow of activation between levels together with within-level inhibition between competing candidates.

In contrast to Grosjean's model (Grosjean, 1997) but like the IC model, Dijkstra and van Heuven (1998) have proposed a model for word recognition in bilinguals (BIA, the **B**ilingual **I**nteractive **A**ctivation model) in which the resolution of competition between word candidates in both languages can be differentially inhibited top-down on the basis of language. Novel to the BIA model is the use of language nodes. Each node collects activation from

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its respective lexicon and suppresses all words in the other lexicon. This device allows the asymmetric inhibition of words in the two languages. Word forms in L1, for instance, can be more inhibited than word forms in L2. These language nodes can be pre-activated reflecting a particular task. The model captures a wide range of data on visual lexical decision tasks and other tasks, and it shows that responses are a function of the task situation, the nature of stimulus material, as well as the expertise of the bilingual (see, for example, van Heuven and Dijkstra, 1997).

In terms of the IC model, the language nodes achieve two functions. First, they are functionally equivalent to language tags (since they identify representations that are to be subject to control). However, currently the locus of control is directly on orthographic input forms, whereas in the IC model the locus is the lemma level and input word forms are not directly inhibited. Moreover, in this sense, the IC model involves reactive inhibition whereas the BIA model does not. Language nodes are analogous to a control schema in that they are external to the system under regulation, are governed by a higher-order system (not currently modelled in BIA) that sets their starting values, and modulate the activity of units within the system top-down. Language nodes differ from the language task schema in the IC model in that they do not directly connect system outputs to responses (responses are read from the activation of units) and unlike the IC model they are not in a relationship of reciprocal inhibition for tasks such as language-specific lexical decision. In this sense, the locus of any switch cost is solely within the bilingual lexico-semantic system and not in the regulating schema.

These models, computationally more or less developed, account for a range of data within a particular task domain (speech perception, visual word recognition, speech production), but they do not currently address the range of tasks that the bilingual lexico-semantic system is required to fulfill. In that sense, they lack the relevant control structure to allow them to model different tasks. The IC model differs by attempting to specify the mechanisms of control (language task schemas and the SAS) and in the means of control (reactive inhibition of specified tags on lemmas). The BIA model is one computational model that is perhaps most amenable to the kind of control structure proposed here, since it uses the idea of top-down inhibition to achieve effects, but the principle of such a structure seems widely applicable.

Future directions and implications

Top-down control

In the IC model the supervisory attentional system (SAS) plays a number of roles. How these roles are performed needs to be specified. In the first instance, it would be helpful to gain more evidence on its role in regulating task performance. The IC model proposes that once established a language task schema can be triggered bottom-up but needs to be monitored to ensure appropriate levels of performance. Language switching within the same task will be affected when the SAS is required to carry out other control operations concurrently, such as monitoring the completion of other goals. Switching between languages tasks, where the same input (e.g., an English word) can evoke either task (e.g., naming versus translating), should be compromised as well.

The IC model supposes that individuals can prepare to perform a given task but that, since inhibition operates reactively, when speaking L2 alternative competitors will become available in L1. Where individuals have elected to code-switch because, for instance, a particular idea can be lexicalized directly in one language but not in the other then dysfluency will be eliminated precisely because there is no competitor. In contrast, when bilingual speakers who routinely use both their languages are required to speak just one of them, as in the experimental situation described by Grosjean (1997), dysfluencies and involuntary language mixing can arise and such effects should increase with additional load on SAS.

Resolution of the mechanism of intentional code-switching requires spelling out how conceptual representations are mapped onto to linguistic representations. Crucial here will be an exploration of the role of attention (and the SAS) in organizing and maintaining non-linguistic representations for mapping.

Tag inhibition

The selection mechanism operates on language tags associated with lemmas. An open question is whether lemmas might possess two tags: one for reception and one for production. A further question concerns how fluency in a language alters the inhibitory mechanism. Undoubtedly we will need to consider both the link between concept and lemma and the link between lemma and word form.

Capacity-effects A language task schema prioritises the processing of stimulus (it is a means of directing and allocating attention, see Van Der Heijden, 1996, for task control in visual attention). Consider a situa-

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tion such as word translation. La Heij et al. (1990) showed interference in translation when a semantically related distractor, presented after the onset of the word, was in the language into which the word was to be translated. The IC model also predicts interference from a distractor when it is in the same language as the target. Consider forward translation. Given the activation of an L1→L2 translation schema, the distractor will capture the translation schema too, since its tag matches its perceptual conditions. In consequence, individuals must verify that they are translating the right item if they are to avoid error. Miller (1997) found that individuals do sometimes translate a distractor word when it is in the language of the target, but never when it is not. They are also more likely to name the distractor when it is in the language required for production.

However the effects of a distractor on translation time and on subsequent responses will depend on whether or not it is actually processed. Like other models (e.g., MacWhinney, 1997), the IC model presumes that functional subsystems are capacity constrained. It follows that if processing of the target demands the capacity of the system, distracting information will not be processed within the time interval for response and so will not interfere with processing and be subject to reactive inhibition (see Lavie and Fox, 1997, for a pertinent unilingual experiment).

Functional control circuits and neuroanatomical systems

The IC model envisages that bilingual individuals perform as they do by selecting and coordinating language task schemas into functional control circuits that in turn modulate the mental representations of word meanings and word forms. It follows that it should be possible to examine these circuits (or rather their effects) using functional imaging methods and so advance the cognitive neuroscience of bilingualism. We have begun an exploration of these circuits using positron emission tomography, PET (Green, von Studnitz and Price, 1997). German-English bilinguals were scanned whilst reading or translating unrelated, visually presented words. We found (1) that forward translation relative to backward translation increased activation in some parts of the region mediating the semantic processing words consistent with the revised hierarchical model, (2) that relative to reading, translation increased activation in the anterior cingulate which is an area activated in Stroop tasks and associated with the inhibition of prepotent responses (Posner and DiGirolamo, in press), and (3) that alternately switching between forward and backward translation relative to translating consistently in one direction induced increased subcortical activation consistent with the involvement of these regions in implementing the actions specified by language task schemas.

Conclusion

This paper has addressed the question of how bilingual individuals control the use of their lexico-semantic system. The IC model shares commonalities with existing proposals but amplifies them by specifying the locus, the means and the mechanism of selection so that bilinguals can perform a range of different language tasks.

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