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Lexical Access Across Languages: A Multinomial Model of Auditory Distraction.

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Abstract

Recall in many types of verbal memory task is reliably disrupted by the presence of auditory distracters, with verbal distracters frequently proving the most disruptive (Beaman, 2005). A multinomial processing tree model (Schweickert, 1993) is applied to the effects on free recall of background speech from a known or an unknown language. The model reproduces the free recall curve and the impact on memory of verbal distracters for which a lexical entry exists (i.e., verbal items from a known language). The effects of semantic relatedness of distracters within a language is found to depend upon a redintegrative factor thought to reflect the contribution of the speech-production system. The differential impacts of known and unknown languages cannot be accounted for in this way, but the same effects of distraction are observed amongst bilinguals, regardless of distracter-language.

Keywords: Auditory distraction; bilingualism; memory; MPT models.

Introduction

Auditory distraction is a simple and inevitable fact of everyday experience, stemming from the role of audition as the "sentinel of the sense" (Handel, 1989; Jones, Hughes & Macken, 2010). A considerable body of experimental data has been amassed, particularly with regard to immediate serial memory (e.g., Jones et al, 2010), indicating that – as a predictor of disruption experienced to the primary task – the lexical content of verbal auditory distracters is less important than the acoustic properties of the signal. For example, to reliably disturb immediate serial recall it is necessary for an auditory stream to consist of multiple, varying items – a single repeated item is much less disruptive (Jones & Macken, 1993). Nevertheless, given the verbal nature of most primary tasks shown to be vulnerable to interference from auditory distracters, it would be surprising if no effect of the lexical properties of the distracters was ever observed.

One task which reliably shows more disruption from meaningful verbal distracters that are semantically related to the material being studied than from semantically unrelated material is categorical free recall. In this task, participants are asked to recall, in any order that occurs to them, a series of items all drawn from the same semantic category (e.g., a fruit, a vegetable, or a four-footed animal) which are presented to them visually, one item at a time. Recall in this task is disrupted by the presence of auditory-verbal distracters but is disrupted more when these distracters are drawn from the same category as the to-be-recalled material. Participants are always asked to ignore anything they may hear, and are never tested on the content of the auditory stream. Results obtained within this task show the extent, and nature, of the processing to which the auditory distracters are subjected. Similarities and differences between results obtained with category free-recall and with identical distracters applied during immediate serial recall also indicate the generality, and specificity, respectively, of both the auditory distraction effect and memory models which aim to account for this effect.

The Schweickert (1993) model.

The model tested in this study is Schweickert's (1993) multinomial model of immediate recall. This model has previously been applied to short-term memory for serial order, in which items must be recalled in the order in which they appeared and are scored as incorrect if an item appears in the wrong position in the serial recall protocol. This model was able to successfully account for the interaction in serial recall data between the frequency of words within the English language (the word frequency effect) and the point at which they were presented in a to-be-recalled list (Hulme, Roodenrys, Schweickert, Brown, Martin & Stuart, 1997). The same model also accounted for a distracter-word frequency effect, that is an effect on immediate serial recall of whether an auditory distracter – presented concurrently with the visual presentation of the to-be-recalled list – was of high or low frequency, with low frequency words causing the most distraction (Buchner & Erdfelder, 2005). As such, the model is a useful one for examining the effects of lexical properties of the auditory distracters, and how these might interact with lexical processing of the to-be-recalled items.

The multinomial model is conceptually straightforward, the structure of the model is given in Figure 1. An item is either directly recalled in an intact form, with probability i, or else the representation of the item exists only in a degraded form and it must be redintegrated, or reconstructed, which is only possible with probability r.

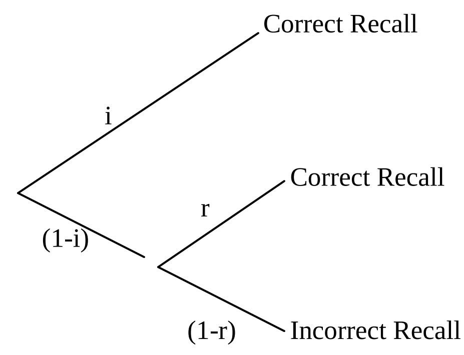

Figure 1. Diagrammatic representation of Schweickert's (1993) multinomial processing tree model.

The form of the model thus allows for two means by which items can be correctly recalled – they may already exist in an "intact" form and be readily available, or they may require reconstruction. If both of these processes fail, the item cannot be recalled. The model has thus far been applied only to immediate serial recall – that is recall commonly considered to be from "short-term memory" but the existence of two distinct processes, each underlying recall in a different way, calls to mind earlier models previously applied to free recall (e.g., Atkinson & Shiffrin, 1968) which also assumed dual components to recall, so it is of interest to examine whether Schweickert's model for serial recall can also be applied to free recall, and in particular the free recall of items from within a single category, which will require the model to generate the well-known serial position function typical of free recall, with primacy and extensive recency (Murdock, 1962), rather than the serial recall curves, with extensive primacy and limited recency, generated by Buchner and Erdfelder (2005) and Hulme et al. (1997).

Lexicality and recall.

As with all multinomial models, the goodness-of-fit between the model and the data is assessed by finding the values for the free parameters (*i* and *r*, in this instance) which produce expected data closest to those observed in behavioral testing. A goodness-of-fit test then determines whether the expected values differ significantly from the observed data (Bachelder & Reifer, 1999). In Hulme et al's (1997) study, *i* was held constant across simulations of different experimental conditions but allowed to vary across serial position to produce the serial position curve indicative of serial recall. That is, for a 7-item to-be-recalled list, different parameter values would exist for i_1, i_2, ...i_7, but these would be identical regardless of experimental condition. *r* was held constant within an experimental condition but allowed to vary across conditions. Hulme et al. (1997) argued that variation of *r* across experimental condition reflected the effect of word frequency upon the redintegration process, with representations of higher-frequency words supporting the redintegration more effectively than representations of low-frequency words (so $r_{\textit{high-frequency}} > r_{\textit{low-frequency}}$). It was assumed that verbal short-term memory is essentially a by-product of processes involved in speech perception and speech production (Hulme, Maughan & Brown, 1991), with redintegration an integral part of speech production, representing the "clean-up" of noisy representations (e.g., within an underlying connectionist network). Similarly, Buchner and Erdfelder (2005) concluded that the word-frequency of the *distracters* must impact upon the probability of retrieving an intact representation (*i*) because a model varying *r*, but with equivalent values of *i* across experimental conditions differed significantly from the data, whereas the expected data from a model with equivalent *r* but varying *i* across the experimental conditions, such that $i_{\textit{high-frequency distracter}} > i_{\textit{low-frequency dsitractor}}$ were statistically indistinguishable from the observed data. Buchner and Erdfelder (2005) conclude in favor of an account in which, "low-frequency distracter words require more processing resources that could otherwise have been used for keeping the memory representations of the target words active and intact" (p. 89).

The study by Buchner and Erdfelder (2005) is curious in that there is no necessary *a priori* reason why low-frequency distracters should attract more attention, or require more processing resources, than high frequency distracters - as these authors are careful to note. Previous studies, however, all used immediate serial recall rather than – as studied here – categorical free recall which draws upon semantic memory and appears to be more sensitive to the lexical properties of the auditory distracters than serial recall (Marsh, Hughes & Jones, 2008). In particular, auditory distraction may also occur within a semantic-memory fluency task in which speech production processes presumably play a large part (Jones, Marsh & Hughes, 2012). On this basis, and using the logic employed by Hulme et al. (1997), if it is possible to apply the Schweickert (1993) model to categorical free recall then the lexical effects of the auditory distracters should be most evident on the *r* parameter, reflecting interference with speech production systems, rather than the *i* parameter which might be interpreted – as, for example, by Buchner and Erdfelder (2005) – as a more general effect, possibly the result of an attentional mechanism drawing off processing resources.

Modeling Recall and Disruption Within and Across Languages

To test these possibilities and simultaneously test the generality of the Schweickert (1993) model, the model was applied to a set of data obtained from English monolinguals and Welsh-English bilinguals. Bilinguals were used to test the possibility that distraction effects associated with the meaning of speech cannot be inhibited, and by extension the idea that the meaning of speech cannot be ignored. The free recall task was presented in one language (English) with speech distracters in either English or Welsh. The distracting speech (in either English or Welsh) consisted of words related to the same subject, or to a different subject. The typical finding is that both unrelated and semantically related speech (distracter words from the same category as the to-be-recalled items) give a distraction effect, but that there is a greater distraction effect for related speech (Neely & LeCompte, 1999). The effect, even for unrelated speech, is lexical rather than acoustic, because non-words and sinewave speech tokens do not disrupt recall (Marsh et al., 2008).

Where does the disruption originate? If the effect of related speech is conceptual in nature, originating from the organization of the speech planning and production system, then one might expect bilinguals to show equivalent disruptive effects of the meaning of the words regardless of their language of origin (English or Welsh). Conceptual effects of the irrelevant speech arising from the disruption of speech organization in this way should be reflected in reductions of the *r* parameter of the model. Alternatively, if the effect is a non-specific lexical/attentional effect akin to that reported by Buchner and Erdfelder (2005) then the bilinguals might be expected to perform more like monolinguals when the irrelevant speech accesses a lexicon (Welsh) other than the one they are employing for the focal task (English). Any residual difference between the two groups, or between the disruption caused by related and unrelated speech should be accountable in terms of the *i* parameter, with lexical/attentional effects reducing the values of this parameter for those conditions that show the most disruption.

For the experiment, twenty-eight English monolinguals and twenty-eight Welsh-English bilinguals each viewed 28 trials of 12 target words, in English, visually-presented for free recall. Stimuli were chosen from semantic categories of the Van Overschelde, Rawson, and Dunlosky (2004) category norms. Items from positions 13-24 in the category-norm lists were used to form target lists and items from positions 1-12 were used as distracters. On half the trials, the auditory distracters were taken from the same category as the targets (e.g., both sets of stimuli were types of animals, and no "shape" exemplars were presented). On the remaining trials, the distracter items were taken from one category of the pair (e.g., fruit) and targets from the other category (e.g., carpenter's tools). Additionally, half of the distracters were presented in English, and half in Welsh, yielding four separate conditions each experienced by both English monolinguals and Welsh-English bilinguals: English unrelated distracters (EU), English related distracters (ER), Welsh unrelated distracters (WU) and Welsh related distracters (WR). Space precludes a full analysis of the behavioral results, but a bar chart of the overall impact of distracters on both groups is given in Figure 2.

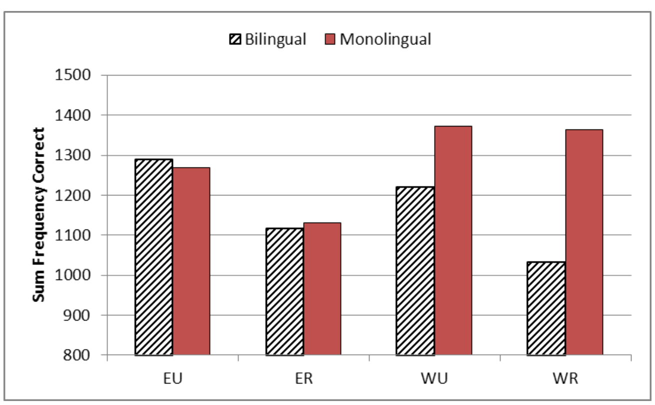

Figure 2. Total frequency of correct recalls across all conditions, summed across serial positions.

Unrelated distracters across languages.

As with Hulme et al. (1997) and Buchner and Erdfelder (2005) *i* was allowed to vary across serial position, thereby implementing the serial position function, but there was a single value for *r* regardless of serial position. multiTree software (Moshagen, 2010) was used to implement the models. In what follows, only models which fit the data are presented graphically.

Examining first the unrelated speech condition for bilingual participants, that is distracters – presented in either English or Welsh – semantically unrelated to the English language targets, the results could be modeled by assuming that neither *i* nor *r* varied across conditions with no significant difference between observed and expected results, G^2 = 15.67, *df* = 11, *p* = .15. This confirms the viability of the Schweickert model for categorical free recall and shows that – for Welsh-English bilingual participants – semantically unrelated distracters have an equivalent effect upon free recall of English words regardless of the language of the distracter.

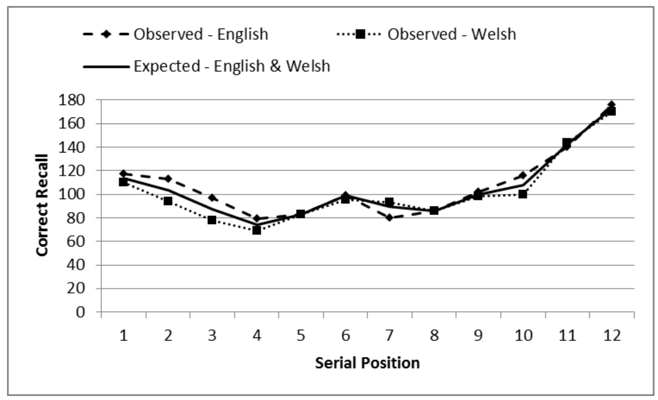

Figure 3. Frequency of correct recalls across serial position by Welsh-English bilinguals for unrelated distracters in English and Welsh. Expected values according to the MPT model are given by the solid line.

For the English monolinguals, a similarly constrained model differs significantly from the data, G^2 = 33.95, *df* = 11, *p* < .001. Thus, for English monolinguals, there is a difference between unrelated English and unrelated Welsh words as distracters. Relaxing the constraints upon the model by allowing *r* to vary across conditions does not improve the fit of the model, G^2 = 30.6, *df* = 10, *p* < .001. Thus, whatever effect the presence of unrelated verbal distracters in a known language (which have a lexical status) has over the effect of distracters in an unknown language (for which no lexical entry exists), cannot be accounted for within the Schweickert model by a redintegration process. Unfortunately, it is not possible to test the effects of similarly freeing the constraints upon the *i* parameter, as investigated by Buchner and Erdfelder (2005), because varying *i* across conditions as well as serial positions imposes too few constraints on the model (Bachelder & Reifer, 1999).

Related distracters across languages.

Applying the model to bilingual English and Welsh speakers exposed to irrelevant distracter speech in either English or Welsh that was semantically related to the English language to-be-remembered stimuli, a model in which *i* varied across serial position but *i* and *r* were identical regardless of the language of the distracter provided a good fit to the data, $G^2 = 8.67$, $df = 11$, $p = .65$. Thus, the distraction effects for bilinguals can be modeled using the same parameter values regardless of the language in which the distracters were presented.

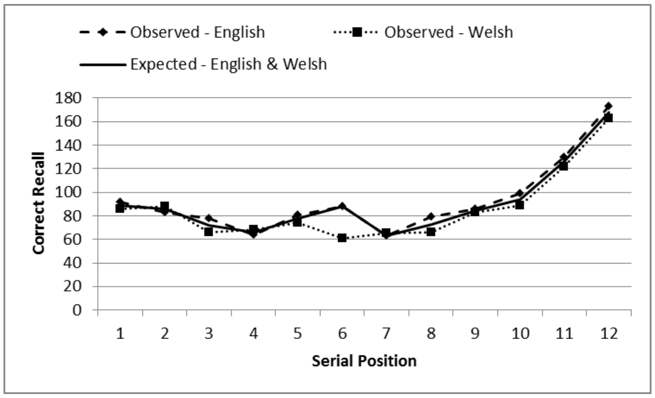

Figure 4. Plot of frequency of correct recalls by Welsh-English bilinguals for semantically related distracters in English and Welsh. Expected values according to the MPT model are given by the solid line.

Unsurprisingly, a similar attempt to model the impact of semantically-related auditory distracters in both English and Welsh on monolingual English speakers was unsuccessful, with the best-fitting model differing substantially from the data, $G^2 = 60.27$, $df = 11$, $p < .001$. Allowing *r* to vary between Welsh and English distracter conditions was also insufficient to substantially improve the fit of the model, $G^2 = 26.62$, $df = 10$, $p = .003$. Thus, in terms of the Schweickert (1993) model, the extra impact, upon a visual-verbal free recall task, of an auditory distracter being in a known language must be upon factors other than redintegration. This is true regardless of whether the auditory distracter is unrelated, or semantically related, to the to-be-remembered targets.

Comparing unrelated and related distracters within languages.

In addition to looking at the effects of bilingualism upon auditory distraction when the distracters are presented in different languages, it is also of interest to compare the effects of distracters *within* a single language. Using the model to investigate the effects of shifting the language of distracters has revealed that the language of the distracter is irrelevant provided it is a known language (Figures 2-4) and that the difference between known and unknown language distracters cannot be captured by a single redintegrative factor. This is consistent with reports by Buchner and Erdfelder (2005) that the frequency of occurrence of words presented as distracters impacted upon the *i* parameter and not the *r* parameter, which they interpret as an attentional effect. However, there are *a priori* reasons to suppose that the difference between semantically-related and unrelated distracters *could* be captured by just such a single, redintegrative factor.

Hulme et al. (1991, 1997) argued that – in immediate serial recall – the effects of word frequency, captured by the *r* parameter in the Schweickert model, reflect the operation of a speech production system yoked into supporting recall. In an investigation of the effects of distraction upon a verbal fluency task of the kind frequently used to explore the speech production system, Jones et al. (2012) found an effect of semantically-related speech. Thus, it seems reasonable to suggest,

1) In free recall as in serial recall, speech production systems may play a role – perhaps by supporting covert articulatory rehearsal. This may particularly apply to categorical free recall, free recall of items from specific, reasonably circumscribed semantic categories.
2) If so, the effects of specifically semantically-related distracters might be traceable to this system via their impact upon the *r* parameter in the model.

Applying the model to the data, this time for the effects of related and unrelated English speech upon free recall by monolinguals, a model that does not differ significantly from the data is obtained by varying only the parameter *r* between the unrelated and related speech conditions, $G^2 = 15.51$, $df = 10$, $p = .11$. The fit of the model is given in Figure 5. To ensure that this fit was not possible simply because there was no difference in the data between the effects of related and unrelated speech, parameter *r* was constrained to be equivalent in both conditions. The resulting model differed significantly from both the previous model, $\Delta G^2 = 11.84$, $df = 1$, $p < .001$and the data, $G^2 = 27.35$, $df = 11$, $p = .004$.

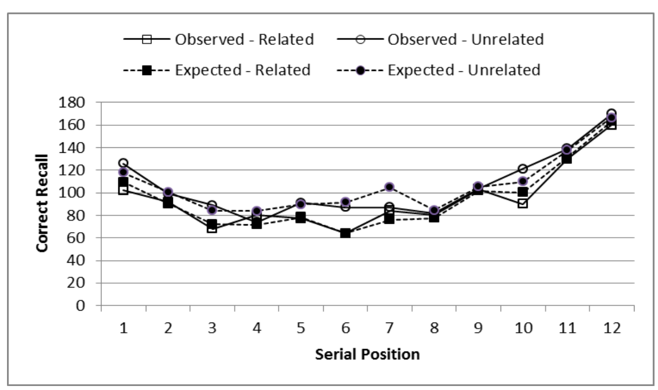

Figure 5. Correct recalls by English monolinguals for semantically related and unrelated distracters in English.

Expected values according to the MPT model are given by the dashed lines and observed values by the solid lines.

Finally, the model was applied to the performance of Welsh-English bilinguals in the presence of English and Welsh distracters that could be either semantically-related, or unrelated to the target lists. Constraining the values of i to be equivalent regardless of whether the distracters were semantically related or not, but allowing the values of r to vary, resulted – as in the case of the English monolinguals – in a model that did not differ significantly from the data observed, $G^2 = 20.67$, $df = 20$, $p = .42$. This was defined as the baseline model, and the output of this model is shown, for Welsh and English, in Figures 6a and 6b.

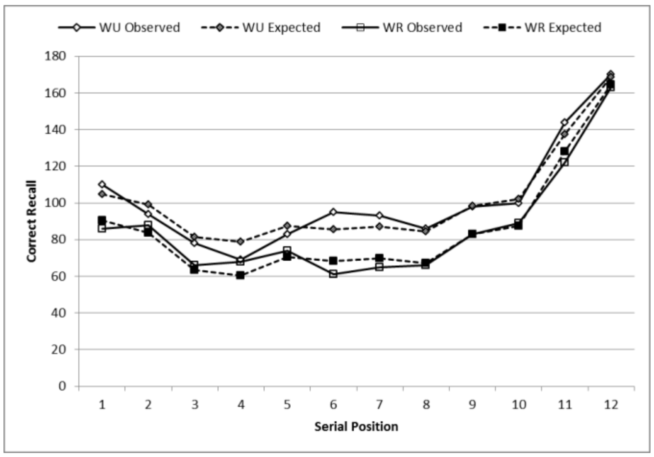

Figure 6a. Frequency of correct recalls across serial position by Welsh-English bilinguals for semantically related (R) and unrelated (U) distracters in Welsh (W). Expected values according to the MPT model are given by the dashed lines, and observed values by the solid lines.

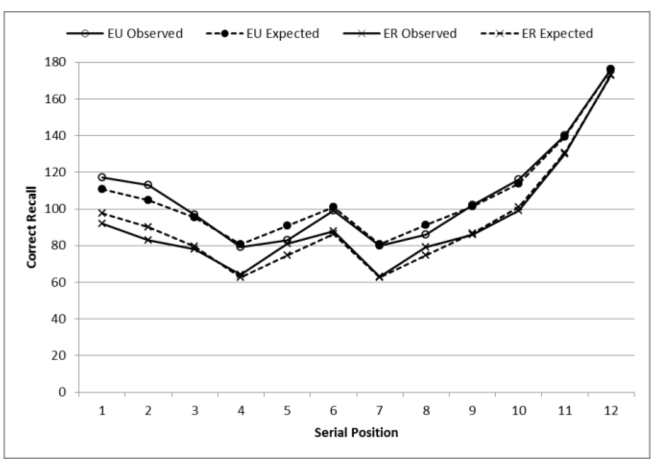

Figure 6b. Correct recalls by Welsh-English bilinguals for semantically related (R) and unrelated (U) distracters in English (E). Expected values according to the MPT model are given by the dashed lines

Additionally constraining the r values for semantically-related speech distracters to be equivalent across languages, and likewise constraining r for unrelated distracters to be equivalent across languages, produced a model that did not differ significantly from the baseline model, $\Delta G^2 = .007$, $df = 2$, $p = .996$, nor from the data, $G^2 = 20.67$, $df = 22$, $p = .54$. However, it was not possible to fit a model in which the r values were equated within languages, regardless of the semantic relationship between distracters (i.e., $r_{EU} = r_{ER}$ and $r_{WU} = r_{WR}$), and were allowed to vary across languages (i.e., $r_E \neq r_W$) – such a model differed significantly from both the baseline model, $\Delta G^2 = 57.16$, $df = 2$, $p < .001$, and from the data, $G^2 = 77..83$, $df = 22$, $p < .001$.

Discussion

The modeling results reported here show that it is possible to extend the Schweickert (1993) model of immediate serial recall to also apply to free recall, consistent with research (such as that of Tan and Ward, 2000), emphasizing similarities between immediate serial and free recall. More importantly, the model also shows that – for bilinguals – the effects of distracters presented in either of their languages are equivalent, even if the primary task on which the impact is observed (free recall in this case) is conducted wholly within one of those languages. Important issues are still to be worked-out with regard to bilingualism, e.g., second-language (L2) proficiency and the age at which L2 was learned, but it is notable that no simple means was found to model, in a similar manner, the effects of English and Welsh distracters on the performance of English-speaking monolinguals. Clearly therefore, for monolinguals, the effects of English and Welsh speech upon categorical free recall performance differed, even when the English distracter speech was semantically-unrelated to the target words. In this, the categorical free-recall task differs from other, notably serial recall, tasks in which foreign speech (including Welsh) has been played to participants, with equivalent effects to speech in their native language (e.g., Jones, Miles & Page, 1990). Whatever the basis for this difference, it cannot be located within a redintegrative stage affected by distracters from known versus unknown languages as manipulation of this parameter did not improve the fit of the model. This is broadly consistent with Buchner and Erdfelder's (2005) finding that varying the word-frequency of distracters within a known language was also more accurately modeled by varying the i rather than the r parameter within the Schweickert (1993) model. Unfortunately, known limitations of the modeling methodology employed (principally, the requirement for the model to be identifiable; Bachelder & Reifer, 1999), prevent further exploration of this issue given the experimental design available (for more discussion of this issue, see Buchner & Erdfelder, 2005).

A more interesting, and more positive, finding arising from the current study is that the semantic effects of distraction within a known language *can* be accounted for in terms of a redintegration stage. Comparison of semantically-related with unrelated English distracter words amongst English monolinguals and Welsh-English bilinguals, and a similar comparison of semantically-related with unrelated Welsh distracter words in the bilingual group, all produce this same result (see Figures 5, 6a and 6b).

This finding is consistent with the data from Jones et al. (2012) showing a semantic distraction effect upon verbal fluency tasks generally considered to tap recall from semantic memory prior to speech-formulation and production, and is consistent with the hypothesis that redintegration reflects a "clean-up" stage in recalling items within the speech production system (Hulme et al., 1991, 1997). "clean-up" may seem to imply simply the filling in of blanks, or correcting of misinformation, within a single already-recalled item by reference to longer-term memory or lexical storage (Levelt, 1999). However, it may fulfill a more important function, namely one of identifying – by means of "cleaning-up" an incomplete or noisy representation – which one of several possible items is the correct one to recall in a particular instance (Nairne, 2003, personal communication). This is likely to be particularly important when, as in the current situation, recall is always from a list in which all of the target items are drawn from the same semantic category and therefore share many semantic and conceptual features. Under such conditions, identifying the correct item from several possible candidates is likely to be particularly important.

In this instance, it seems reasonable to suggest that the presence of semantically-related distracters compromises the redintegrative process at the level of retrieval of the word-concept, resulting in greater distraction than is seen with semantically-unrelated distracters. This suggestion is further supported by the fact that bilinguals show a semantic distraction effect from a language other than the one in which they are nominally working (that is, the English-language memory task). This implies that although the effects of speech on categorical free recall may be lexical (Marsh et al., 2008) the specific effects of semantic distraction across languages are conceptual, not lexical, in nature.

Acknowledgments

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