Interactivity During Spoken Word Recognition: Evidence from Bimodal Bilinguals

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Abstract

We explore the role of top-down information in language processing by investigating parallel language activation in bimodal bilinguals, who are fluent users of a spoken and a signed language. In an eye-tracking study, bimodal bilinguals showed activation of their signed language while receiving input in English only. Since spoken and signed languages do not share structure, the results suggest that linguistic information can be readily transmitted across modalities, and that parallel language activation can be driven by top-down processes.

Keywords: bilingualism; ASL; language co-activation; top-down processing; eye-tracking; visual world paradigm

Introduction

The architecture of the language system is determined by the way that information flows among levels of processing. Language processing may involve both bottom-up/feed-forward and top-down/feed-back mechanisms (Rapp & Goldrick, 2000; Navarette & Costa; 2009). However, exclusively feed-forward systems may also be capable of explaining language processing *without* the aid of feed-back mechanisms (Hagoort & Levelt, 2009; Levelt, Roelofs, & Meyers, 1999; McQueen, Jesse, & Norris, 2009; Norris, 1994). Proponents of language systems that recruit top-down mechanisms face the difficulty of separating the impact of top-down information from that of bottom-up information. When both forms of information are present, it is difficult to disentangle the unique contributions each may make to language processing. To understand the role of top-down mechanisms during language processing, the influence of top-down pathways must be measured in isolation. One possible way of limiting the impact of bottom-up information is by investigating language processing in bimodal bilinguals.

Unlike unimodal bilinguals, who use two spoken languages, bimodal bilinguals are fluent in a spoken and a signed language. Research on unimodal bilinguals has revealed non-selective language effects, wherein unimodal bilinguals activate both of their languages in parallel (Blumenfeld & Marian, 2007; Marian & Spivey, 2003; Weber & Cutler, 2004). For example, when a Russian-English bilingual hears the English word “marker,” she will also make eye movements to items that are phonologically similar in the non-target language (e.g., Russian) such as “marka” (stamp), suggesting that her Russian is simultaneously activated. This effect appears to be bottom-up in nature – as auditory input enters the language system, it non-selectively activates lexical items in both languages based on structural overlap. Critically, a dual-language bottom-up pathway cannot exist in bimodal bilinguals, as their languages do not utilize the same structural input. The cross-modal nature of bimodal bilingualism therefore allows for the direct investigation of top-down mechanisms in isolation.

If bimodal bilinguals co-activate their two languages in the absence of form overlap, it would suggest that language co-activation can be driven by top-down information, and would require a system capable of activating the non-target language via top-down or lateral connections. Models that consider exclusively bottom-up information for lexical activation or selection (such as the Shortlist Model, Norris, 1994) are unlikely to be able to explain this result, as they limit activation to items that exist in the same modality as the target. Therefore, a bimodal bilingual, when faced with single-modality input (e.g., spoken English), should not activate the signed language.

However, recent research indicates that bimodal bilinguals do co-activate their languages. For example, hearing ASL-English bilinguals produce speech and signs simultaneously (Emmorey, Borinstein, Thompson, & Gollan, 2008), deaf ASL-English bilinguals show interference from sign-language while processing written-English (Villwock, Wilkinson, Bailey, Kroll, Morford, & Piñar, 2009), and late-learning Dutch-Sign Language of the Netherlands bilinguals show interference from English while processing SLN signs (Van Hell, Ormel, van der Loop, & Hermans, 2009). In addition to clarifying the role of top-down mechanisms in language processing, language co-activation in bimodal bilinguals would suggest that linguistic information is readily transmitted across modalities, such that two unrelated languages can be activated simultaneously, even when phonological information from one of the two languages is absent.

The current study used an adapted visual world paradigm to examine parallel language processing in normal-hearing, ASL-English bilinguals. Investigating whether languages that do not share modality are co-activated in bimodal bilinguals can provide insight into the influence of top-down mechanisms on language processing and the architecture of the language system in general, as well as reveal the extent to which linguistic information is modality independent.

Method

Participants

Twenty-six participants were tested (thirteen ASL-English bilinguals, M_{age}=33.2, SD=11.8 and thirteen English monolinguals, M_{age}=23.9, SD=9.8). An additional five participants were not included in the analysis – three due to failure to display sufficient proficiency in ASL, and two due to technical error with the eye-tracker. All participants completed the *Peabody Picture Vocabulary Test* (PPVT-III; Dunn & Dunn, 1997) to assess their English vocabulary skill. No differences were found between bilinguals (M=108.2, SD=9.9) and monolinguals (M=111.8, SD=9.4; t(24)=0.96, p=.35). Information on the participants' language background was obtained via the *Language Experience and Proficiency Questionnaire* (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007). On a scale of 1-10, where 10 means "fluent," bilinguals rated their ASL abilities at 8.5 for production, and 8.8 for comprehension, indicating a high degree of ASL proficiency. All participants reported normal hearing and vision.

Materials

Twenty-two minimal sign pairs were developed by choosing two signs that matched on three of four ASL-phonological parameters – handshape, location in space, motion, and orientation of the palm (Brentari, 1998). These sign pairs represented the target and competitor items in our competitor condition. For example, the signs for "cheese" and "paper" overlapped in handshape, location, and palm orientation, but differed in the motion of the sign. Target and competitor signs did not differ significantly in English word frequency [t(38)=-1.654, p=.106] (obtained from the SubtLexus database; Brysbaert & New, 2009). In addition, twenty-two control items and 110 filler items were chosen based on their lack of phonological overlap to the target in both ASL and English. Control items were used in place of competitor items in the control condition. Control signs also did not differ from target signs in English word frequency [t(38)=-1.027, p=.311]. In the experiment, each item was represented by a black and white line drawing. In each condition, four black and white drawings were displayed on a computer screen in the corners of a 3x3 grid. The words were recorded at 44.1 Khz, 32 bits by a female, monolingual speaker of English, in sentence context as the final word in the phrase "click on the _____." Recordings were normalized such that the carrier phrase was of equal length for all target sentences, and the onset of the target word always occurred at 600 ms post onset of the sentence. Recordings were amplitude-normalized.

Design

The current study used a 2x2 Mixed design, with group (bilingual, monolingual) as a between-subjects factor, and condition (competitor, control) as a within-subjects factor. The dependent variables include the proportion of looks (1 for a look, 0 for no look) and duration of looks (percent of time per trial spent looking at an item). There were twenty-two competitor trials, containing a target, a competitor item that overlapped with the target in ASL phonology, and two fillers (Fig. 1). Every competitor trial had a corresponding control trial, in which the content and location of the target item and two filler items were identical, but where the phonologically-overlapping competitor item found in the competitor trial was replaced with an unrelated control item. This allowed for the comparison of looks to a specific location in the display as a function of the presence or absence of a phonological competitor. There were also forty-four filler trials, containing a target and three phonologically unrelated items.

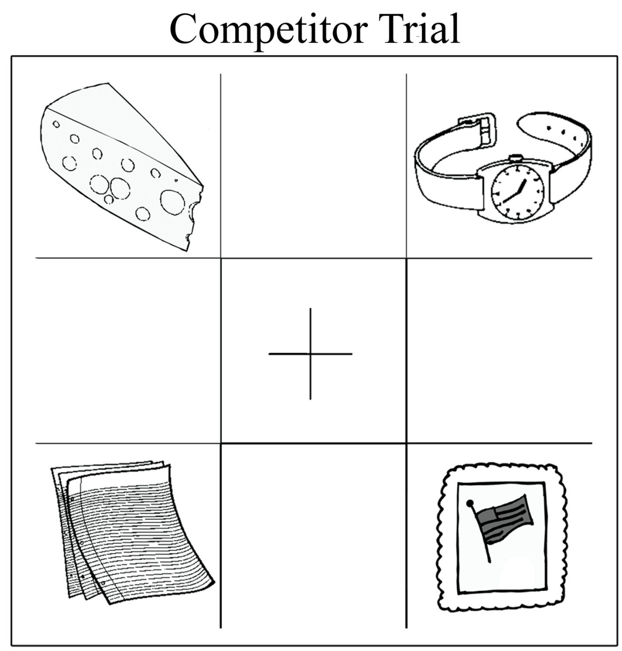

Figure 1: Example of a Competitor Trial. Participants eye-movements were recorded while they were instructed in English to "click on the cheese." At the same time, a phonologically related competitor in ASL ("paper") was present in the display.

Procedure

After informed consent was obtained, participants viewed a video clip displaying the experimental instructions in ASL performed by a native signer of ASL. Following the instructions, participants were fitted with an ISCAN eye-tracker to measure the location of their gaze during the eye-tracking portion of the experiment. Instructions were again provided, in both written and spoken English, followed by five practice trials meant to familiarize participants with the task. Auditory stimuli were presented over headphones and appeared synchronously with picture stimuli. Participants were told that they would hear instructions to choose a specific object in the visual display, and should click on the object that best represents the target word. Participants' eye-movements were recorded. After the eye-tracking portion of the experiment, all participants completed the PPVT and the LEAP-Q. In addition, bilingual participants were presented with a list of words and asked to provide the American Sign Language translations. Bilinguals provided correct translations for 95.2% of the words (M=62.8/66, SD=2.5).

Results

Frequency of Looks

We measured both the proportion and duration of looks to competitor and control items. Bilinguals looked more at competitor items than at control items, and looked more at competitor items than monolingual participants. Repeated measures Analyses of Variance (ANOVAs) revealed a significant Group x Condition interaction for both the proportion [$F(1,24)=27.284$, $p<0.001$; Fig. 2] and duration [$F(1,24)= 23.285$, $p<0.001$; Fig. 3] of looks. Bilinguals looked at competitor items more than at control items [$t(12)=7.62$, $p<0.001$] and for a longer period of time [$t(12)=5.925$, $p<0.001$], signifying that bilinguals activated phonologically related competitors more than phonologically unrelated controls. No differences were found in the monolingual group for either the proportion [$t(12)=-0.95$, $p=0.362$] or duration [$t(12)=-0.16$, $p=0.87$] of looks. Bilinguals also looked at competitor items more than monolinguals [$t(24)=5.58$, $p<0.001$] and for a longer period of time [$t(24)=3.512$, $p<.01$], while both groups looked at control items equally [proportion=$t(24)=1.18$, $p=0.248$; duration=$t(24)=-.73$, $p=0.47$], verifying that bilinguals activated phonologically related items more than monolinguals. Means and standard errors are illustrated in Table 1.

Table 1: Means and Standard Errors of the Proportion and Duration of Looks (%).

	Proportion (%)		*Duration (%)*	
	Comp.	Control	Comp.	Control
Bilingual	66.9 (*2.8*)	51.6 (*3.5*)	12.9 (*0.8*)	7.7 (*0.6*)
Monolingual	42.9 (*3.2*)	45.5 (*3.8*)	8.5 (*0.9*)	8.6 (*1.0*)

Time Course

Analysis of the bilingual time-course was consistent with the overall looks analysis, with bilinguals looking at competitors more than at control items. In contrast, monolinguals looked at competitor and control items equally across time. The activation curves were divided into 100 ms windows, beginning with the time window between -600 and -500 ms (which signified the first 100 ms after the onset of the picture), and ending with the window between 1900 and 2000 ms. Three-by-two repeated-measures ANOVAs were performed on each individual window, with time (1, 2, 3) and condition (competitor, control) as within-subjects factors. Significant effects of condition were found in each of the four 100 ms time windows between 0 ms (word onset) and 400 ms, between 1000 and 1100 ms, and between 1300 and 1400 ms (all $ps<0.05$); in all cases, bilinguals showed more looks to competitor items than control items. Similar analyses performed on the monolingual activation curves revealed no

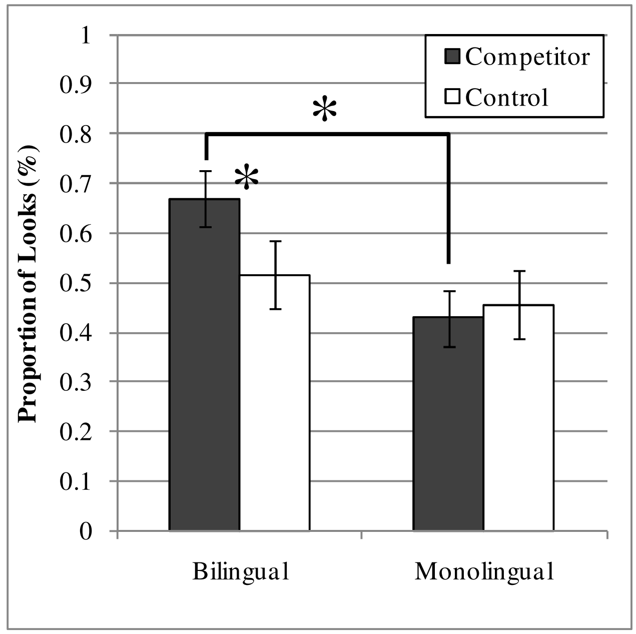

Figure 2. Proportion of Looks (%)

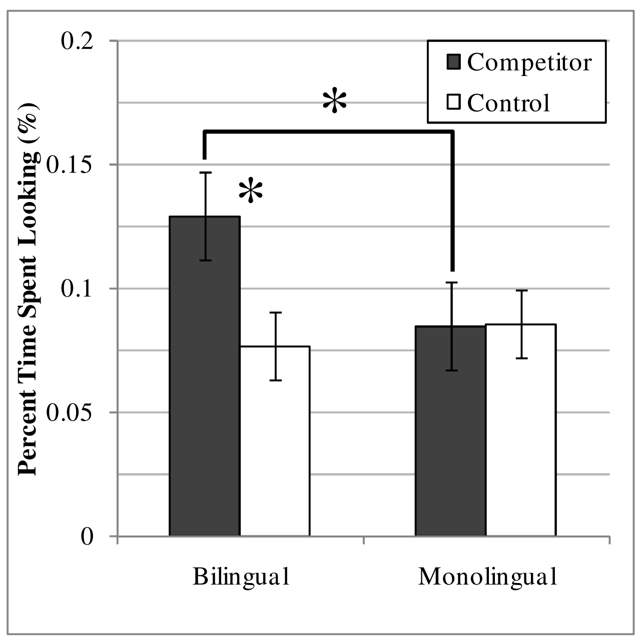

Figure 3. Duration of Looks (%)

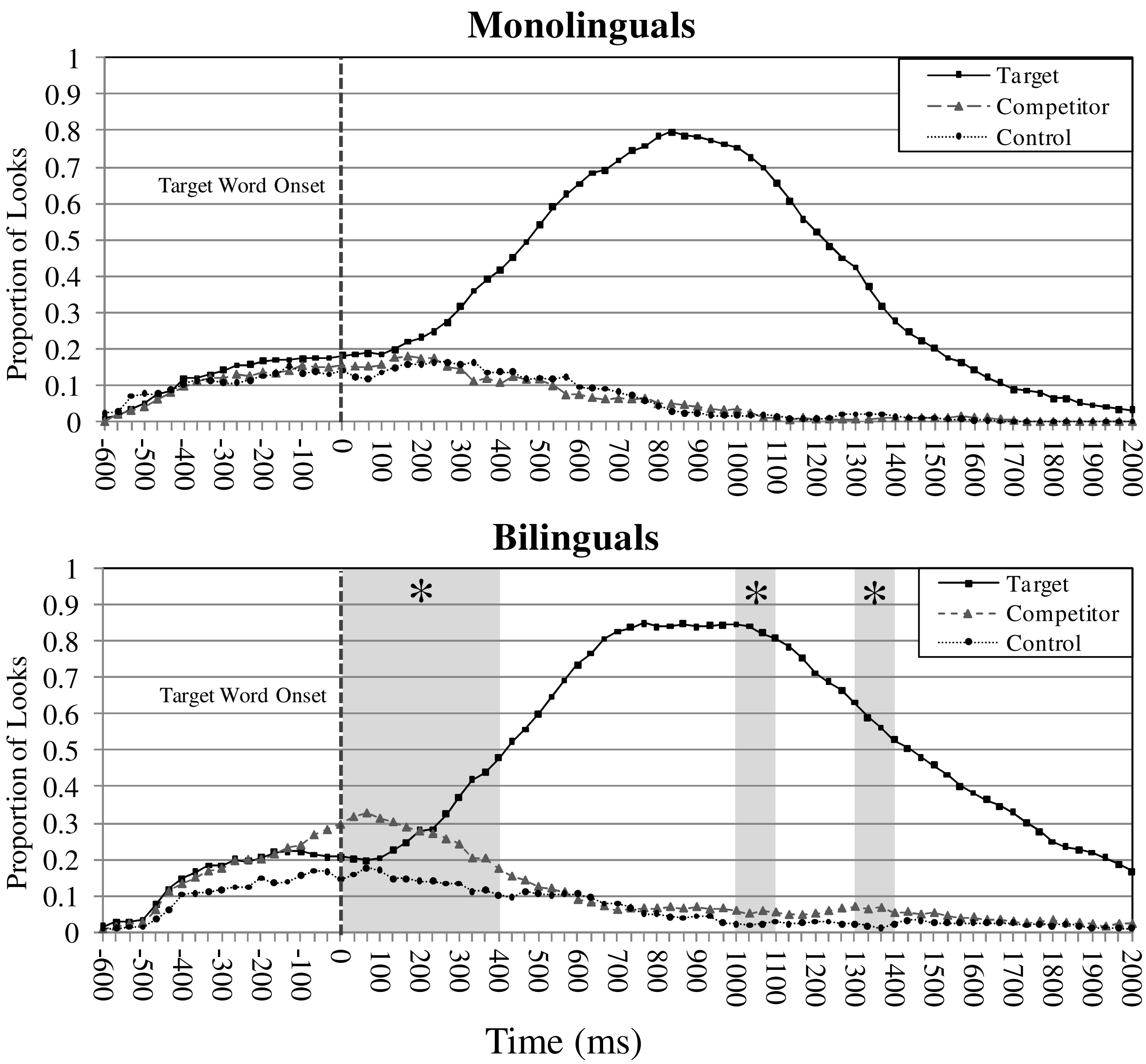

Figure 4. Time-course data for Monolingual (top) and Bilingual (bottom) participants, showing activation curves for proportion of looks to target, competitor, and control items across time. The negative 600 time point represents onset of the picture stimulus, and the 0 time point represents onset of the target word. Shaded areas indicate windows where looks to competitor and control items differed at $p<0.05$

significant effects of Condition for the monolingual group in any time window (all *p*s > 0.1), suggesting that monolinguals did not look more at competitor items than controls (see Figure 4).

It is possible that the effect seen in the late windows (1000-1100 ms and 1300-1400 ms) is a product of residual activation from the early window. To ensure that the late-window effects were not due to lingering activation from the early window, the proportion of late-window looks to competitors *with* a look to targets or competitors in the early-window was compared to late-window looks *without* earlier target or competitor fixations. If there was a higher proportion of late-window looks when the early window contained a look to either the target or competitor than when it did not, it would suggest that late-window activation was due to residual activation from the early window. However, both instances showed the same proportion of looks, $t(12)=1.04$, $p=.377$, suggesting that the results seen in the late-windows are not due to previous activation in the early-window.

Discussion

The results of the current experiment provide evidence for a modality-independent language system that utilizes top-down pathways during processing by revealing parallel language activation in bimodal bilinguals. Specifically, bilinguals looked more to items with ASL translation equivalents that overlapped phonologically with the target item than to items with translation equivalents that did not overlap, suggesting that phonologically overlapping competitor items were more activated than unrelated controls. In turn, monolinguals looked at competitor items and unrelated control items equally. This pattern was found in the overall looks analysis and in the duration of looks analyses, as well as within specific time windows during processing. The results suggest that even though the bilingual participants received no ASL input, they nevertheless activated their sign-language during the experiment.

The finding that bimodal bilinguals coactivate their languages indicates that lexical items from two distinct languages do not require surface-level overlap in order to be simultaneously activated. Previous studies on unimodal bilinguals have relied on bottom-up information as the force behind parallel language activation – words activate phonologically similar words, regardless of language. If parallel activation is driven purely by overlap at the phonological level, then the bimodal participants should not have shown cross-linguistic activation. Instead, the connection between ASL and English likely exists at the semantic level, since the two languages do not share phonological or lexical items. Semantic representations, once activated, appear to be able to feed back to the lexical levels of *both* signed and spoken languages, resulting in parallel activation.

However, the mechanisms that underlie parallel processing in bimodal bilinguals are unclear. Examination of the time-course showed that at the moment of the onset of the target word, competitor items were activated more than control items in the bilingual group. If the target word has yet to be presented in full, how is it possible that bilinguals would show increased activation of competitor items? Prior to onset of the word, bilinguals view the display containing all four images for 600 ms. Bilinguals may automatically activate the corresponding semantic concepts due to visual input. This activation can feed back ASL lexical levels and activate phonologically similar lexical items. The phonologically related items may then continually activate one another until target selection occurs.

The process of top-down activation of the non-target language in bimodal bilinguals can also be initiated by linguistic input. The initial semantic representation could be activated by the incoming English target word, rather than by visual stimuli. When the semantic representation is activated, it feeds back to the lexical representations in both English and ASL, thereby activating phonologically similar ASL signs and their corresponding semantic representations. It is important to note that in this account, parallel activation is still a product of top-down processes – the linguistic input should activate English only. However, bimodal bilinguals clearly activate their ASL during the task.

Coactivation may also occur via lateral links between translation equivalents. As an English word is presented, it may activate its ASL translation via direct excitatory connections at the lexical level, which may in turn activate phonologically similar ASL items. While this account does not involve top-down processes, it is also not exclusively bottom-up, and requires a system capable of interaction across languages, *within* a single level of processing. However, the strength of within-level translational connections in bimodal bilinguals is unclear. For instance, bimodal bilinguals do not show enhanced performance on executive control tasks, which has been found in unimodal bilinguals. Emmorey, Luk, Pyers, and Bialystok (2008) suggest that since a bimodal bilingual's two languages utilize separate modalities, they do not compete to the same extent as two spoken languages. Therefore there is less need for executive control of the non-target language in bimodal bilinguals. One could argue that the lack of competition between a spoken and a signed language may indicate that bimodal bilinguals do not develop cross-linguistic connections in the same manner as unimodal bilinguals. It is not yet clear whether the connections between translation equivalents, or the way in which they are processed, are similar in unimodal and bimodal bilinguals.

Regardless of whether parallel activation in bimodal bilinguals is due to top-down effects or lateral connections at the lexical level, it is clear that the processes that underlie language coactivation in bimodal bilinguals differ from those of unimodal bilinguals. While coactivation in unimodal bilinguals relies more on phonological overlap across two languages, no such overlap exists within the processing architecture of bimodal bilinguals. Therefore, the finding that bimodal bilinguals coactivate their languages implies a system where top-down or lateral processes are capable of governing cross- linguistic activation. Our results also indicate that language information may be readily transmitted across modalities, such that two highly unrelated languages can be activated simultaneously. Thus, the language system should be considered modality-independent and able to process linguistic information equally, regardless of whether it is auditory or sensorimotor in nature.

Moreover, there is reason to believe that a system of this nature is not unique to bimodal bilinguals, and may provide a window into more general language processing. Unimodal bilinguals and monolinguals have shown robust cross-modal effects as well (for a review, see Marian, 2009), and semantic-competition effects from eye-tracking provide evidence for rapid and highly robust lexical-semantic interaction (Huettig & Altmann, 2005; Yee & Sedivy, 2006). In addition, when bimodal bilinguals produce code-blends, they do so in the same fashion as unimodal bilinguals would code-switch, with the added benefit of being able to produce speech and signs in tandem, suggesting similarities in the underlying mechanisms of production for unimodal and bimodal bilinguals (Emmorey et al., 2008). It is possible that the top-down pathways utilized by bimodal bilinguals are present in unimodal bilinguals and monolinguals as well, but are overshadowed by more immediate bottom-up effects.

The results of the current study indicate that bimodal bilinguals activate both of their languages simultaneously via a cross-linguistic lexical-semantic loop where top-down information from the conceptual level feeds back to lower levels of processing in both languages, regardless of modality. The results have further implications for the architecture and processing dynamics of the language system, bilingual and monolingual alike, suggesting that language information can be freely accessed across modalities, and that top-down mechanisms can have a strong influence on language processing.

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