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Repetition reduction during word and concept overlap in bilinguals ☆

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ABSTRACT

In natural conversation, speakers often mention the same referents multiple times. While repeated referents are produced with less prominence than non-repeated referents, it is unclear whether prominence reduction is due to repetition of concepts, words, or a combination of the two. In the current study, we dissociate these sources of repetition by examining bilingual speakers, who have more than one word for the same concept across their two languages. Three groups of Korean–English bilinguals (balanced, English-dominant, Korean-dominant) performed an event description task involving repetition of referents within a single language (i.e., repetition of word and concept) or across languages (i.e., repetition of concept only). While balanced bilinguals reduced prominence both within and across languages, unbalanced bilinguals only reduced prominence when repetition occurred within a language. These patterns suggest that the degree to which words and concepts are linked within a speaker's language system determines the source of repetition reduction.

Introduction

During conversation, people tend to mention a topic multiple times, and this repetition affects the acoustic form of an utterance (Arnold, 1998). The first time a word occurs in a conversation, production tends to be more exaggerated. For example, you may say, "I have a *cat*" placing emphasis on the word "*cat*." For the rest of the conversation, you may be less careful with your pronunciation of the word "cat," and as a result, subsequent mentions of "cat" will tend to have shorter duration and lower intensity compared to the first production. This phenomenon is known as repetition reduction. Repetition reduction is a well-characterized occurrence in which expressions that refer to repeated or given referents are produced with less prominence (i.e., shorter duration and lower intensity) than expressions that refer to non-repeated or new referents (Aylett & Turk, 2004; Bard et al., 2000; Bell, Brenier, Gregory, Girand, & Jurafsky, 2009; Fowler, 1988; Fowler & Housum, 1987; Galati & Brennan, 2010; Kahn & Arnold, 2012; Lam & Watson, 2010; Pluymaekers, Ernestus, & Baayen, 2005; Watson, Arnold, & Tanenhaus, 2008).

While it is known that speakers reduce prominence for repeated expressions, it is unknown where this repetition reduction manifests along the production stream, because repetition can occur at multiple levels in the production process (Baumann & Riester, 2013; Fowler, 1988; Lam & Watson, 2014). Though there are competing models of spoken word production, most models identify at least three

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important levels in the production process: a concept level, a word level, and a phoneme level[1] (e.g., Costa, Caramazza, & Sebastian-Galles, 2000; Dell, 1986; Dell & O'Seaghdha, 1991, 1992; Levelt, 1989; Levelt et al., 1999; for a review, see Rapp & Goldrick, 2000), and it is possible for repetition reduction to take place at each of these levels. Fig. 1A–C provide schematics of these levels of representation across different models of production.

The production process begins with the activation of concepts representing a speaker's intended meaning (e.g., CAT). Activation from the concept level is then mapped onto corresponding words at the word level. At this point, multiple words may be active and the system needs to choose which word(s) to send for further processing. For example, the concept of CAT may activate both the words "cat" and "kitten" due to overlapping semantic information. Activation from the word level then flows downward to activate phonemes for production (e.g., /k/, /æ/, /t/ for "cat"). Within a normal conversation, repeatedly naming an object would involve repeated activation of the concept, repeated activation of the word, and repeated activation of the phonemes for a word. Theoretically, repetition reduction could be rooted at any and all of these levels.

However, there is some evidence to suggest that repetition reduction is not due to phoneme level repetition. In a study by Fowler (1988), participants produced words that could be primed by either the same word or by a homophone. Homophones are words that completely overlap at the phoneme level (e.g., "seller" and "cellar"). Fowler found that while repeated words were reduced in prominence, words that were preceded by a homophone prime (i.e., phoneme repetition) were not reduced. This pattern suggests that repetition reduction is not due to repetition at the phoneme level, but rather the result of repetition at an earlier stage of the production process, specifically, at the levels of concepts or words.

Synonyms, or words that have nearly identical meanings but differ in form (e.g., couch and sofa), might offer a possible approach to determining if repetition reduction is due to repetition at the concept level or repetition at the word level. Indeed, synonyms were also tested for repetition reduction in the Fowler (1988) study described above, but the results were inconclusive because synonym primes resulted in durations that were in-between those of same-word primes (i.e., word repetition) and unrelated primes (i.e., no repetition), but that did not significantly differ from either prime type. This null result may be due to the fact that Fowler elicited synonym production via reading, as it is not clear that reading a word would necessarily activate its synonyms in the same way as with more spontaneous production, such as object naming (e.g., Costa et al., 2000). Synonyms may also be problematic because speakers may have a context-dependent preference for one synonym over another, and having chosen to use a particular word, speakers have a tendency to reuse that word when referring to the same referent (Brennan & Clark, 1996; Garrod & Anderson, 1987). Moreover, the introduction of a new word may lead listeners to interpret the word as referring to a different object (e.g., Metzing & Brennan, 2003) because, according to the principle of contrast, a difference in form would be expected to mark a difference in meaning (Clark, 1990, 1997). Even if listeners interpret the word as referring to the same referent, a change of referring expression may lead listeners to think of the referent differently, thereby altering the concept (Almor, 1999; Clark, 1990; Lam & Watson, 2014). In both cases, the concept may have changed as a result of the word change, making it difficult to separate concept and word repetition.

Given the inconclusive findings from work with synonyms, it remains unclear whether repetition reduction is primarily driven by concept repetition, word repetition, or a combination of the two. Bilinguals, who are known to code-switch between their two languages (Costa et al., 2000; Gollan & Ferreira, 2009; Kroll, Bobb, Misra, & Guo, 2008), may offer another way to separate these two forms of repetition. Models of bilingual language production suggest that a bilingual's two languages have mostly shared or highly overlapping concepts but separate words for each language (e.g., Costa, 2005; Costa et al., 2000; Kroll & Stewart, 1994). Because bilinguals have more than one word for any concept (i.e., one word for each language), it is possible to separate concept-level repetition from word-level repetition. Unlike with synonyms, where changing the word may imply a different concept, changing from a word to its translation equivalent can be motivated by a change in the response language while preserving the meaning. Indeed, Monsell, Matthews, and Miller (1992) used the language-switch paradigm to examine whether prior production of a word primes production for its translation equivalent. In the first phase of their study, word production was elicited from Welsh-English bilinguals via sentence completion (e.g., "a pine is a type of ___") in either Welsh (half the participants) or English (half the participants). Following the sentence completion task, participants completed a separate picture-naming task using Welsh. Speakers demonstrated repetition reduction for words primed in the same language (Welsh → Welsh) but did not for words primed in a different language (English → Welsh). Given these results, Monsell, Matthews, and Miller argued that concept repetition alone is not enough to elicit repetition priming.

While Monsell et al. (1992) did not find repetition reduction across languages, their paradigm may not have been well suited for examining repetition reduction because the primes from the first phase of their study did not describe the same referents as the words in the second phase. In their study, primes were words that were elicited via definition prompts or via sentence completion, which differ from the later picture-naming task. Thus, Monsell, Matthews, and Miller's results cannot speak to whether conceptually-driven repetition reduction will occur when there is also referent repetition. By contrast, in more natural conversation, concept repetition usually occurs when the same referent is mentioned multiple times, meaning that the method employed in this study involved less repetition of the referent than is typically observed in natural

[1] We will use the terms "concepts," "words," and "phonemes" throughout the paper, but these would correspond to "semantic features," "lexical nodes," and "phonemes" in models by Dell and O'Seaghdha (1991) and Dell and O'Seaghdha (1992) and to "lexical concepts," "lemmas," and "lexemes" in models by Levelt (1989) and Levelt, Roelofs, and Meyer (1999).

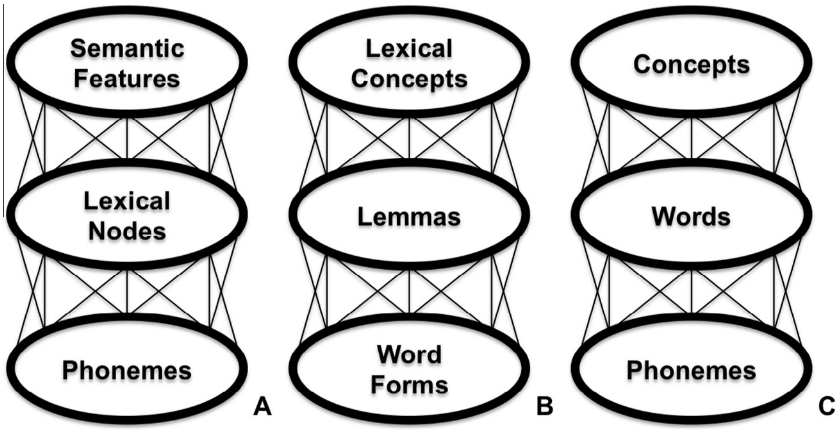

Fig. 1. Schematics depicting the connections between the three major levels of representation for different models of word production (adapted from Rapp & Goldrick, 2000). The lines represent the connections between concepts and words and between words and phonemes. Fig. 1A presents the three major levels of production using terminology from Dell and O'Seaghdha (1991, 1992): semantic features map onto lexical nodes, which in turn map onto phonemes. Fig. 1B presents the three major levels using the terminology from Levelt (1989): lexical concepts map onto lemmas, which then map onto word forms. Fig. 1C presents the three major levels using our unified terminology: concepts map onto words, which then map onto phonemes.

speech. Additionally, their paradigm was suboptimal because it elicited isolated words rather than multi-word phrases and sentences. Prior studies suggest that repetition reduction effects are stronger in sentences (e.g., Fowler, 1988), particularly when the word is in the same grammatical position (Terken & Hirschberg, 1994).

Finally, the lack of repetition reduction across languages in Monsell et al. (1992) could be due to the language backgrounds of the participants in their study. Though it is possible to separate concept-level repetition from word-level repetition in bilinguals, concepts may not be equally linked to words across both languages. In the case of unbalanced bilinguals (that is, bilinguals with unequal proficiency in their two languages), there may be stronger connections between concepts and words for the dominant language than for the less-dominant language, while in balanced bilinguals concepts may be equally linked to words in each language (Costa & Santesteban, 2004; Gollan & Ferreira, 2009; Kroll & Stewart, 1994). Monsell et al. (1992) did not report any information regarding language balance for their bilinguals. If their bilinguals were unbalanced, prior activation from the concept level may not have primed words in both languages equally, which could have led to the observed null effect of repetition in the language switch (concept repetition) condition. Furthermore, unbalanced bilinguals may also have had difficulty switching from using a word in the dominant language (English) to using a word in a less dominant language (Welsh), which may have obscured any concept repetition effects. We address these concerns by examining repetition reduction in both balanced and unbalanced bilinguals.

In our study, concept-level repetition and word-level repetition were dissociated by using a two-part event description task in which the participant sequentially produced two sentences that both referred to the same object. Repeated productions occurred both within (i.e., both sentences are produced in the same language) and across languages, (i.e., each sentence is produced in a different language). If concept-level repetition alone can lead to repetition reduction, then speakers should reduce the prominence of repeated objects regardless of whether the repetition occurs across the bilingual's two languages or within a single language. In contrast, if repetition reduction is due only to word-level repetition, then speakers should reduce the prominence of repeated objects only when the object is repeated within a single language. A third possibility is that repetition operates at both the concept level and the word level. In this case, there may be reduction for repeated targets both when there is a language switch as well as when repetition occurs within the same language, but the effect would be greater for repetition within the same language.

As a secondary aim of the study, we examine whether repetition reduction is dependent on the connection strength between concepts and words by comparing balanced vs. unbalanced bilinguals. Because language imbalance may affect the relative level of activation for words across the two languages, the degree to which concepts and words are linked within a language may impact repetition reduction. While balanced bilinguals should have relatively similar activation of words in both languages for any given concept, unbalanced bilinguals may preferentially activate words for the dominant language over words in the less dominant language. Therefore, if repetition reduction is mediated by the availability of the words, balanced bilinguals may show repetition reduction for concept repetition by reducing prominence for repeated objects both within and across languages, while unbalanced bilinguals may only show an effect for word repetition, where repetition only leads to reduction within a single language, but not across languages.

Method

Participants

Forty-eight adult bilingual speakers of Korean and English (mean age = 22.06; *SD* = 3.53) participated in the experiment after providing informed consent. Participants had lived in an English speaking country for an average of 10.32 years ($SD = 5.62$) and lived in a Korean speaking country for an average of 11.73 years ($SD = 6.71$). All participants were university students currently studying and residing in the United States. All participants completed the *Language Experience and Proficiency Questionnaire* (*LEAP-Q*; Marian, Blumenfeld, & Kaushanskaya, 2007), a self-report questionnaire designed to assess the language profiles of multilingual participants. On a scale of 0–10, participants reported proficiencies (combined speaking and listening proficiency) of 9.05 ($SD = 1.00$) in Korean and 8.96 ($SD = 1.21$) in English.

We separated participants into three groups: balanced bilinguals, Korean-dominant bilinguals, and English-dominant bilinguals. Language balance was determined by relative proficiencies in Korean and English. Sixteen participants were classified as balanced bilinguals with similar proficiencies across Korean and English (a difference of 1 or less; mean difference = 0.00, $SD = 0.68$, $t(15) = 0.00$, $p > .10$). Sixteen participants were classified as Korean-dominant bilinguals with Korean proficiency that was more than one point greater than their English proficiency (mean difference = 2.19; $SD = 0.93$, $t(15) = 9.42$, $p < .001$). The other sixteen participants were classified as English-dominant bilinguals with English proficiency that was more than one point greater than their Korean proficiency (mean difference = 1.91; $SD = 0.66$, $t(15) = 11.5$, $p < .001$). There was a significant difference in proficiency balance across the three groups (p's < .001). Table 1 presents the average proficiencies in Korean and English for each of the three groups of bilinguals. Forty-four participants listed Korean as the first language, one participant listed English as the first language, and three participants listed Korean and English as acquired simultaneously. The average age of acquisition (AOA) for Korean was 0.50 years ($SD = 0.77$) and the average AOA for English was 5.71 years ($SD = 3.66$). Table 1 presents the average AOA of Korean and English in each of the three groups. Individual participant responses are presented in Appendix A.

Design

The study involved a two-part event description task adapted from Lam and Watson (2010) in which participants used two sentences to describe events involving objects displayed on a computer screen (e.g., "The apple is shrinking … the *apple* is flashing."). The critical word was the name of the object in the second event. We manipulated three factors across each pair of sentences: (1) Whether or not the target object was the same in both events; (2) Whether or not the target object in the second event was named in Korean or English; and (3) Whether or not participants switched languages between the first and second events (henceforth: stay vs. code-switch trials). These three factors were crossed in a 2 (target object, same vs. different) × 2 (response-language, Korean vs. English) × 2 (language-switch, stay vs. code-switch) design, leading to eight conditions relating to the status of the second item.

Materials

This experiment used images from Rossion and Pourtois (2001), which are colored versions of the images from Snodgrass and Vanderwart (1980). Of the 260 pictures in the set, we removed images if their Korean names were English loan words or if their Korean names had initial phoneme overlap with their English counterparts (e.g., "펜" – [pen] and "pen"), resulting in 106 remaining images. Of the remaining images, 104 were used as targets in the experiment: 96 in experimental trials and eight in practice trials. From the 104 images used, we created 52 image pairs such that the images' names contained no initial phoneme overlap within or between Korean and English. Each image pair served as the two possible targets for each trial and pairs were not repeated, resulting in a total of 52 trials. Of these 52 trials, four trials served as practice trials while the remaining 48 were critical trials. These 48 critical trials were split into 24 Korean-response trials and 24 English-response trials. The mean syllable length of the 24 target words in Korean including the case marker was 3.23 (0.67) syllables. In English, the mean syllable length for the 24 target words was 1.73 (0.80). Conditions were presented in a pseudorandomized order such that each of our eight conditions appeared exactly once in each set of eight trials (i.e., Trials 1–8, Trials 9–16, etc.). As there were 48 critical trials and eight conditions, participants saw each condition exactly six times over the course of the experiment. This set of 48 trials constituted the first list of items and conditions. We created another three lists of 48 trials by counterbalancing repetition and code-switching within items across our trial lists. Another four lists were generated by inverting the order of items and conditions in the previous lists, leading to a total of eight different lists of items and conditions.

The language of response was elicited by either a picture of a Korean actress (Son Yejin) or an American actress (Jennifer Aniston). Although no true addressee was present, participants were verbally instructed to treat their response as being directed toward the person depicted. Hence, speakers were asked to use Korean when speaking

Table 1
Participant characteristics.

	Age of acquisition of Korean	Age of acquisition of English	Korean proficiency	English proficiency
Balanced	0.625 (0.72)	5.31 (3.86)	9.41 (0.61)	9.41 (0.82)
Korean-Dominant	0.187 (0.40)	6.63 (4.35)	9.84 (0.30)	7.66 (0.96)
English-Dominant	0.6875 (1.01)	5.19 (2.61)	7.91 (0.66)	9.81 (0.44)

Note: Average age of acquisition and average proficiency for balanced Korean–English bilinguals, Korean-dominant bilinguals, and English-dominant bilinguals as assessed using the *Language Experience and Proficiency Questionnaire* (LEAP-Q). Standard deviations are presented in parentheses.

to a Korean person and English when speaking to an American person. Though some reduction effects are sensitive to the presence of addressees (e.g. Arnold, Kahn, & Pancani, 2012; Rosa, Finch, Bergeson, & Arnold, 2015), repetition reduction has also been demonstrated in the absence of an addressee (Lam & Watson, 2010, 2014). Furthermore, repetition reduction occurs even when the addressee has changed (Bard & Aylett, 2004; Galati & Brennan, 2010; Meagher & Fowler, 2014), suggesting that at least some aspect of repetition reduction is speaker driven.

Displays were presented using MATLAB with the Psychophysics toolbox version 3 (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007) and the CogToolbox for MATLAB (Fraundorf et al., 2014). Participants' responses were recorded at a frequency of 44,100 Hz using a Sennheiser PC 360 microphone headset. The headset was used to control the distance between speakers' mouths and the microphone across trials, as distance can affect the recorded intensity of the sound wave.

Example 1.

Non-repeated, Stay, English: The book is shrinking ... the **apple** is blinking.

Repeated, Stay, English: The apple is shrinking ... the **apple** is blinking.

Non-repeated, Code-switch, English: 책이 줄어든다 ... the **apple** is blinking.
(book shrinking)

Repeated, Code-switch, English: 사과가 줄어든다 ... the **apple** is blinking.
(apple shrinking)

Procedure

When participants first arrived, they completed an electronic version of the *LEAP-Q*. Following the *LEAP-Q*, participants began the event description task.

At the beginning of the event description task, participants were first shown a short video demonstrating the task. After watching the video, participants were visually presented with the task instructions on the computer screen, first in English, and then in Korean. After reading the instructions, participants completed practice trials from four different conditions of the experiment. Upon finishing the practice, participants completed 48 critical trials (without any filler trials). The number of critical trials and the absence of filler trials were based on previous work in the repetition reduction literature (e.g., Lam & Watson, 2014).

At the start of a trial, two objects appeared on the computer screen followed by a picture of either a famous American actress (Jennifer Aniston) or a famous Korean actress (Son Yejin) to establish language mode (see Fig. 2). After three seconds, the picture of the actress disappeared, and one of the objects began shrinking. Participants described this shrinking event[2] in either English or Korean, depending on which actress they saw, and pressed a key to continue. Then, another picture of either Jennifer Aniston or Son Yejin appeared, and one of the objects began blinking (the same two objects from before remained on the screen between events to ensure consistency of referents). Participants described the blinking event and then pressed a key to end the trial. Sample sentences for each English-response condition are presented in Example 1. In each sentence, the critical word is the noun of the second utterance (underlined and bolded). Fig. 2 presents a depiction of the sequence of events in the Repeated Codeswitch English condition.

Data analysis

Across all participants, 157 trials (6.8%) were excluded from analysis either because participants failed to name the target object (4.9%) or because participants used the wrong language when describing the target object (1.9%). Because the events involved only shrinking and blinking, and participants were provided with an example video, there was very little variation in the carrier sentences between trials for any particular participant. Across participants, there was some variation in the carrier sentences used in Korean, as some participants used the dictionary "verb + 다" form, whereas other participants used verb endings from the more formal "verb + ㅂ니다" form. In English, all participants used the verb "shrinking" as the first verb, but some participants used "flashing" as the second verb instead of "blinking."

Participants' utterances in the event description task were hand-transcribed and annotated for prominence analysis in Praat, a speech analysis platform (Boersma & Weenink, 2007). Two fluent Korean–English bilinguals with early exposure to both languages completed the transcriptions. The transcribers marked the onset and offset of the target word as well as the onset and offset of the utterance. For Korean items, transcriptions for the target word included the subject markers (가/이) which are attached to the ends of the nouns in written Korean. Target word onset and offset were identified by a combination of auditory perception and visual inspection of the spectrogram. Transcription duties were separated such that each person transcribed utterances for different sets of participants with an emphasis on within-transcriber consistency. Transcribers were given the following instructions for marking the onset and offset of target words.

[2] Participants were not explicitly told how to describe each event, though a possible sentence structure was provided in the example video.

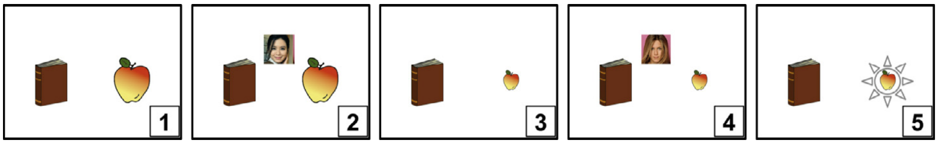

Fig. 2. Depiction of the sequence of events in the event description task from the Repeated Code-switch English condition. Speakers describe the events depicted in Panel 3 (the shrinking event) and Panel 5 (the blinking event).

- For word boundaries that occur at a transition between a vowel and consonant, set the boundary at the end of the pitch period coinciding with a change in amplitude visible in the spectrogram.
- For word boundaries that occur at a vowel–vowel transition, mark the boundary at the midpoint of the vowel transition in the spectrogram and verify perceptually by listening to the sound file before and after the boundary marker.
- When the target word is utterance initial, mark the target word onset at the beginning of the visible change in intensity in the spectrogram from silence to the onset of the word and verify through auditory perception.

For Korean target words, the onset was always utterance-initial while the offset always coincided with a vowel–consonant transition. For English target words, the onset coincided with a vowel–consonant transition when the participant produced a determiner and the target word began with a consonant onset (~87.5% of English targets). For English target word offsets, the offset occurred at a vowel–consonant boundary for all target words that ended in a coda consonant (~75% of English targets).

As is typical in prominence analysis, we present the prominence data both in terms of duration (e.g., Fowler, 1988; Fowler & Housum, 1987; Galati & Brennan, 2010; Kahn & Arnold, 2012) and intensity (e.g., Kochanski et al., 2005; Lam & Watson, 2010, 2014; Watson et al., 2008) because these metrics may be sensitive to different aspects of reduction. Lam (2012, see also Lam & Watson, 2014) argues that intensity may be more sensitive to differences at the concept level of production while duration may be more sensitive to differences at the word and phoneme levels. This would lead to the prediction that intensity is more likely to show a main effect of repetition while duration is more likely to show an interaction between repetition and code-switching.

Analyses on duration were conducted on both the raw duration (ms) for the target word (i.e., the noun used in the second utterance) and the percentage of the utterance length accounted for by the target word (i.e., noun duration/total utterance duration), which we will refer to as "utterance proportion." This second measure of duration provides an estimate of how prominent a target word is within an utterance and accounts for inter-speaker variability in speech duration. If repetition leads to reduction of an entire phrase, utterance proportions may not capture this change, but if repetition affects the target word itself, utterance proportion may be a more sensitive measure of target word reduction. Though prominence differences typically manifest on the stressed syllable of a word in English, in Korean, prominence is a property of the accentual phrase (e.g., Jun, 1993, 1998), which may include only a single word or multiple words (including a full sentence) depending upon speech rate and word length. When the accentual phrase includes the entire sentence, utterance proportions may be less sensitive to this change.

As with duration, analyses on intensity examined both raw and relative measures. Analyses on intensity were conducted on the average intensity of the target word measured in decibels SPL (sound pressure level) and the relative intensity of the target word measured as the percentage difference in intensity from the target word compared to the intensity of the rest of the utterance (i.e., [target intensity–utterance intensity]/utterance intensity). As with relative duration, relative intensity provides a measure of how prominent the word is within the utterance.

Initial analyses were conducted on all participants with repetition, code-switching, and the interaction between repetition and code-switching as fixed effects of interest. We also included response-language (Korean vs. English) and language-balance (i.e., balanced vs. unbalanced) as control variables, but do not report their effects as the initial analyses are focused on whether repetition reduction can occur for concept-level repetition in the absence of word-level repetition. Contrasts for all fixed effects were sum coded.

Following the analyses with all participants, we conducted follow-up analyses examining the effect of language balance (e.g., balanced bilinguals vs. unbalanced bilinguals) on repetition reduction. For follow-up analyses with balanced bilinguals, we considered fixed effects of repetition and code-switching, as well as their interactions with response language modeled as a control variable. For unbalanced bilinguals, we considered fixed effects of repetition, code-switching, response-dominance (i.e., dominant vs. non-dominant language), and participant type (i.e., Korean-dominant bilingual vs. English-dominant bilingual) as well as their interactions. Unlike in the analyses with balanced bilinguals, for unbalanced bilinguals, response-dominance and participant type were modeled as fixed effects because unbalanced bilinguals would be expected to show different patterns of prominence across their two languages.[3] Note that for unbalanced bilinguals we have recoded the "response-language" factor as "response-dominance." This is because the dominance of the response language is more important theoretically for our research questions than the identity of the language itself. As in the main analyses, contrasts for all fixed effects were sum coded.

Analyses were conducted using multilevel modeling with random slopes and intercepts for subjects and items (Barr, Levy, Scheepers, & Tily, 2013). As with analysis of variance

[3] For all reported analyses with unbalanced bilinguals, the patterns for the main effect of repetition and the two-way repetition by code-switching interaction were the same as in models that only considered repetition, code-switching, and the repetition by code-switching interaction.

(ANOVA), multilevel models are able to account for variance from subjects and items; however this method has the additional benefit of being able to account for multiple random factors simultaneously (Baayen, Davidson, & Bates, 2008). For all analyses, we used the maximally converging random effects structure for subjects and items. If the model did not converge, we removed random slope terms from the model starting with the highest order term that accounted for the least variance in the model. Tables 2–4 present the random terms that were included or excluded in each of the maximally converging models for analyses with all participants (Table 2), analyses with balanced bilinguals (Table 3), and analyses with unbalanced bilinguals (Table 4).

The *p*-value estimates were obtained using normal approximation by assuming that the *t* distribution approached a *z* distribution given our number of observations. As this study is focused on the effects of repetition within and across languages, we report the main effect of repetition and the interaction between repetition and code-switching for all analyses. We also report all significant interactions that include the factor of repetition. For significant interactions ($p < .05$) involving repetition, follow-up analyses were conducted to examine the patterns of the interactions by separating analyses for each level of a variable, while retaining all other fixed effects that do not include the separated variable. A complete set of results tables is included in Appendix B.

Results

Concept repetition in the presence and absence of word repetition

Duration

The means for raw duration across all participants are presented in Fig. 3A. For raw duration, there was a significant two-way interaction between repetition and code-switching ($\beta = -54.63$, $SE = 10.13$, $t = -5.39$, $p < .001$). Follow-up analyses examining the effect of repetition across stay and code-switch trials demonstrated that repeated targets were produced with shorter durations than non-repeated targets in the stay condition ($\beta = 32.50$, $SE = 5.08$, $t = 6.39$, $p < .001$) but not in the code-switch condition ($\beta = -11.25$, $SE = 7.49$, $t = -1.50$, $p = .133$). There was also a main effect of repetition: repeated targets were produced with shorter durations than non-repeated targets ($\beta = 9.46$, $SE = 4.42$, $t = 2.13$, $p < .033$).

The means for utterance proportion across all participants are presented in Fig. 4A. The patterns for utterance proportion were similar to raw durations. There was a significant two-way interaction between repetition and code-switching ($\beta = -1.70$, $SE = 0.40$, $t = -4.26$, $p < .001$). When stay and code-switch trials were analyzed separately, repeated targets were produced with smaller utterance proportions than non-repeated targets in the stay condition ($\beta = 1.75$, $SE = 0.27$, $t = 6.50$, $p < .001$), but not in the code-switch condition ($\beta = 0.07$, $SE = 0.32$, $t = 0.23$, $p = .818$). In addition, there was a significant main effect of repetition where repeated targets were produced with smaller utterance proportions than non-repeated targets ($\beta = 0.96$, $SE = 0.22$, $t = 4.32$, $p < .001$).

Intensity

Fig. 5A presents the means for raw intensity across all participants. For raw intensity, there was a significant main effect of repetition in which repeated targets were produced with lower intensity that non-repeated targets ($\beta = 0.24$, $SE = 0.11$, $t = 2.14$, $p = .032$). The interaction between repetition and code-switching was not significant ($\beta = -0.30$, $SE = 0.26$, $t = -1.15$, $p = .250$).

The means for relative intensity across all participants are presented in Fig. 6A. For relative intensity, there was a significant two-way interaction between repetition and code-switching ($\beta = -1.09$, $SE = 0.52$, $t = -2.10$, $p = .036$). Follow-up analyses separating stay and code-switch trials demonstrated that repeated targets were produced with lower relative intensity than non-repeated targets on stay trials ($\beta = 1.02$, $SE = 0.41$, $t = 2.50$, $p = .013$) but not on code-switch trials ($\beta = -0.12$, $SE = 0.32$, $t = -0.37$, $p = .707$). In addition, there was a significant main effect of repetition where repeated targets were produced with lower relative intensity than non-repeated targets ($\beta = 0.75$, $SE = 0.27$, $t = 2.82$, $p = .005$).

Repetition reduction and language balance

When language-balance was added to the models that examined the locus of repetition reduction across all participants, the results indicated that language-balance mediated repetition reduction (see Appendix B). Specifically, there were significant two-way interactions between repetition and language-balance for raw duration ($\beta = 17.61$, $SE = 6.85$, $t = 2.57$, $p = .010$) and utterance proportion ($\beta = 1.00$, $SE = 0.38$, $t = 2.62$, $p = .008$), and there was a significant three-way interaction between repetition, code-switching, and language-balance for relative intensity ($\beta = 2.18$, $SE = 1.00$, $t = 2.17$, $p = .030$). In the next section we present follow-up analyses separating balanced and unbalanced bilinguals to examine the effects of language-balance on repetition reduction.

Balanced bilinguals

Duration

The means for raw duration in balanced bilinguals are presented in Fig. 3B. For raw duration, there was a significant main effect of repetition where repeated targets were produced with shorter duration than non-repeated targets ($\beta = 29.10$, $SE = 5.82$, $t = 5.00$, $p < .001$). The interaction of repetition by code-switching was not significant ($\beta = -22.80$, $SE = 13.70$, $t = -1.66$, $p = .096$).

The means for utterance proportion are presented in Fig. 4B. The pattern for utterance proportion was similar to the pattern for raw duration. For utterance proportion, there was a main effect of repetition where repeated targets were produced with smaller utterance proportions than non-repeated targets ($\beta = 1.53$, $SE = 0.29$, $t = 5.29$, $p < .001$). The interaction between repetition and code-switching was not significant ($\beta = -0.64$, $SE = 0.59$, $t = -1.08$, $p = .281$).

Table 2
Maximally converging random effects structure for models with all participants.

	Subject random effects				Item random effects			
	Raw duration	Utterance proportion	Raw intensity	Relative intensity	Raw duration	Utterance proportion	Raw intensity	Relative intensity
(Intercept)	*	*	*	*	*	*	*	*
Repetition	*	*	*	*	*	*	*	*
Codeswitch	*	*	*	*	*	*	*	*
Language	*	*	*	*				
Balance					*	*	*	*
Repetition:Codeswitch	*	*	*	*	*	*	*	*
Repetition:Language	–	*	–	–				
Codeswitch:Language	*	*	*	*				
Repetition:Balance					*	*	–	*
Codeswitch:Balance					–	–	–	–
Repetition:Codeswitch: Language	–	–	–	–				
Repetition:Codeswitch: Balance					–	–	–	–

Note: Asterisks indicate the slope and intercept terms that were included in the maximally converging model for each metric. Dashes indicate slope terms that were excluded from the maximally converging model for each metric. Empty boxes represent slope terms that are not theoretically possible.

Table 3
Maximally converging random effects structures for models with balanced bilinguals.

	Subject random effects				Item random effects			
	Raw duration	Utterance proportion	Raw intensity	Relative intensity	Raw duration	Utterance proportion	Raw intensity	Relative intensity
(Intercept)	*	*	*	*	*	*	*	*
Repetition	*	*	*	*	*	*	*	*
Codeswitch	*	*	*	*	*	*	*	*
Language	*	*	*	*				
Repetition:Codeswitch	*	–	*	*	*	–	*	*
Repetition:Language	*	–	*	*				
Codeswitch:Language	*	–	*	*				
Repetition:Codeswitch: Language	–	–	*	*				

Note: Asterisks indicate the slope and intercept terms that were included in the maximally converging model for each metric. Dashes indicate slope terms that were excluded from the maximally converging model for each metric. Empty boxes represent slope terms that are not theoretically possible.

Table 4
Maximally converging random effects structures for models with unbalanced bilinguals.

	Subject random effects				Item random effects			
	Raw duration	Utterance proportion	Raw intensity	Relative intensity	Raw duration	Utterance proportion	Raw intensity	Relative intensity
(Intercept)	*	*	*	*	*	*	*	*
Repetition	*	*	*	*	*	*	*	–
Codeswitch	*	*	*	*	*	*	*	*
Language	*	*	*	*				
PartType					*	*	*	*
Repetition:Codeswitch	*	–	–	–	*	–	–	–
Repetition:DomLang	*	–	–	–				
Codeswitch:DomLang	*	–	–	–				
Repetition:PartType					–	–	–	–
Codeswitch:PartType					–	–	–	–
Repetition:Codeswitch: DomLang	–	–	–	–				
Repetition:Codeswitch: PartType					–	–	–	–

Note: Asterisks indicate the slope and intercept terms that were included in the maximally converging model for each metric. Dashes indicate slope terms that were excluded from the maximally converging model for each metric. Empty boxes represent slope terms that are not theoretically possible.

Intensity

The means for raw intensity in balanced bilinguals are presented in Fig. 5B. Unlike with raw duration and utterance proportion, raw intensity showed no clear patterns. The interaction between repetition and code-switching was not significant ($\beta = 0.12$, $SE = 0.44$, $t = 0.29$, $p = .772$) and the main effect of repetition was also not significant ($\beta = 0.28$, $SE = 0.27$, $t = 1.04$, $p = .299$).

The means for relative intensity in balanced bilinguals are presented in Fig. 6B. As with raw intensity, the analyses for relative intensity yielded no significant effects or repetition ($\beta = 0.37$, $SE = 0.61$, $t = 0.60$, $p = .547$) nor a significant interaction between repetition and code-switching ($\beta = 0.45$, $SE = 0.91$, $t = 0.49$, $p = .622$).

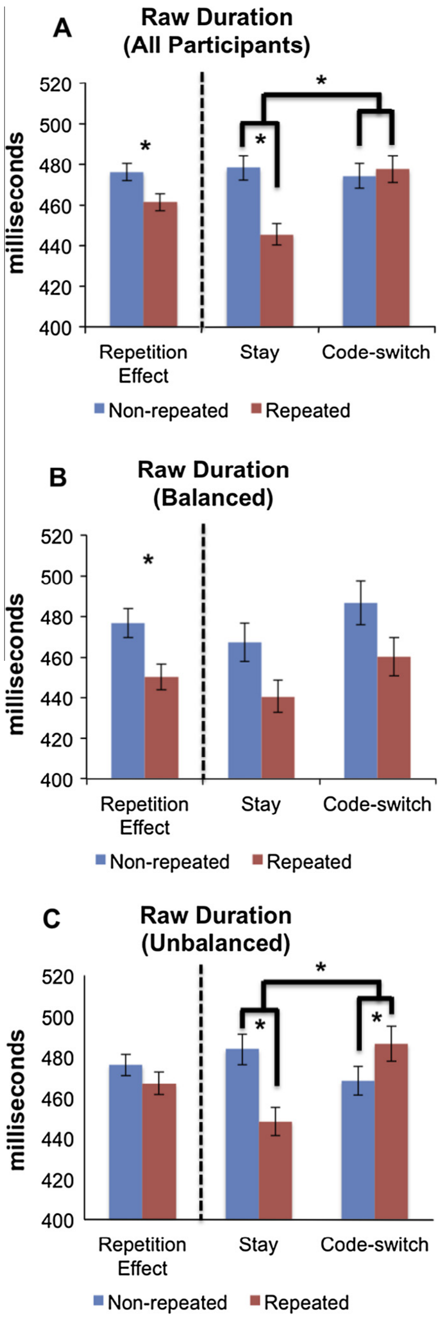

Fig. 3. Average raw durations for words produced by all participants combined (Panel A), balanced bilinguals (Panel B), and unbalanced bilinguals (Panel C). The left side of each chart depicts the main effect of repetition collapsed across Stay and Code-switch trials. Asterisks indicate significant effects ($p < .05$).

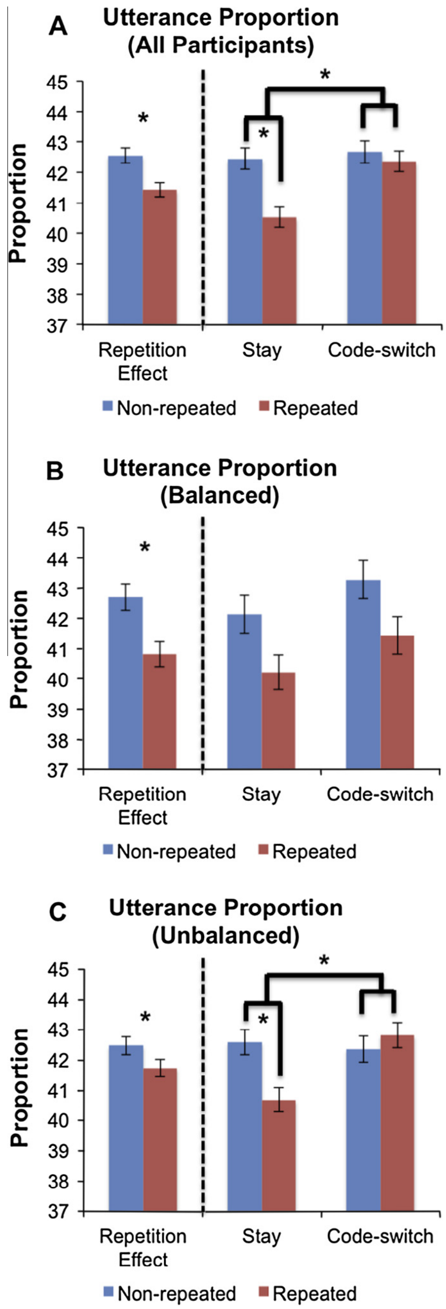

Fig. 4. Average utterance proportions for words produced by all participants combined (Panel A), balanced bilinguals (Panel B), and unbalanced bilinguals (Panel C). The left side of each chart depicts the main effect of repetition collapsed across Stay and Code-switch trials. Asterisks indicate significant effects ($p < .05$).

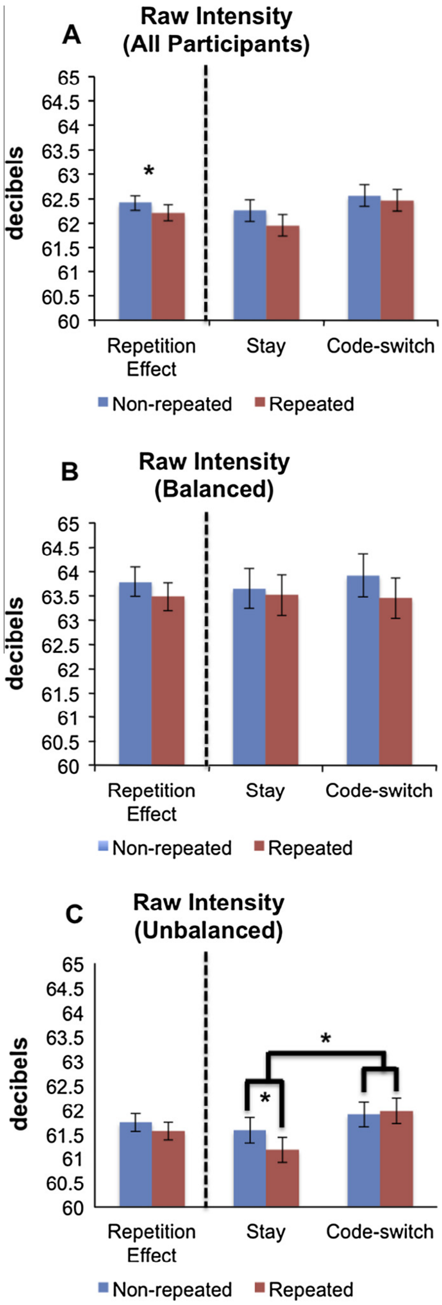

Fig. 5. Average raw intensities for words produced by all participants combined (Panel A), balanced bilinguals (Panel B), and unbalanced bilinguals (Panel C). The left side of each chart depicts the main effect of repetition collapsed across Stay and Code-switch trials. Asterisks indicate significant effects ($p < .05$).

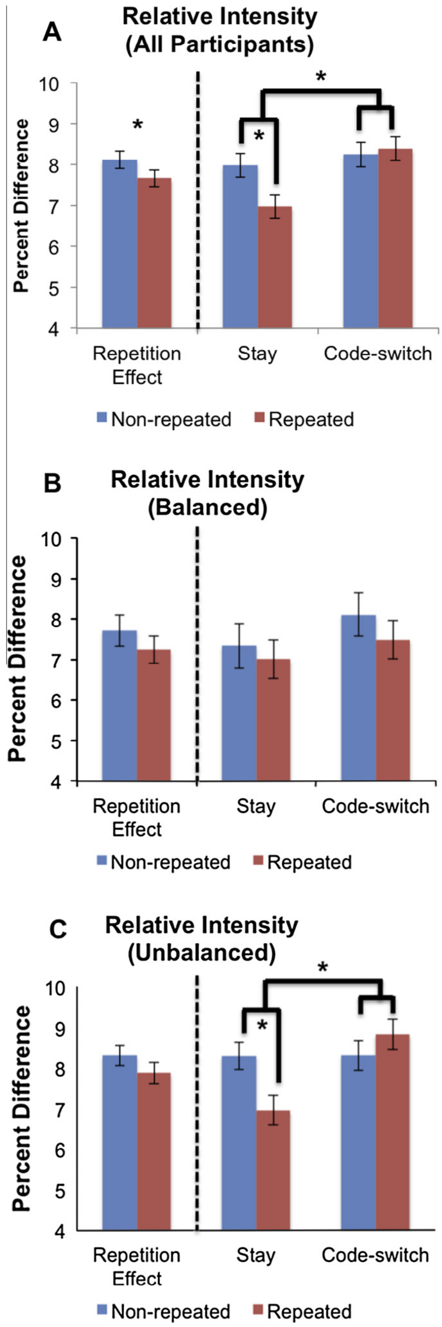

Fig. 6. Average relative intensities for words produced by all participants combined (Panel A), balanced bilinguals (Panel B), and unbalanced bilinguals (Panel C). The left side of each chart depicts the main effect of repetition collapsed across Stay and Code-switch trials. Asterisks indicate significant effects ($p < .05$).

Unbalanced bilinguals

Duration

Means for raw duration in unbalanced bilinguals are presented in Fig. 3C. Unlike in balanced bilinguals, repetition interacted with code-switching in unbalanced bilinguals. For raw duration there was a significant three-way interaction between repetition, code-switching, and response-dominance ($\beta = -45.42$, $SE = 15.47$, $t = -2.94$, $p = .003$). When responding in the non-dominant language, there was a significant repetition by code-switching interaction ($\beta = -49.90$, $SE = 13.23$, $t = -3.77$, $p < .001$). Though repeated targets were produced with shorter durations than non-repeated targets in the stay condition (β = 29.51, SE = 10.16, t = 2.90, p = .004), repeated targets were produced with longer durations than non-repeated targets in the switch condition (β = −42.03, SE = 14.60, t = −2.88, p = .004). When responding in the dominant language, the interaction between repetition and code-switching was not significant (β = −21.26, SE = 12.63, t = −1.68, p = .092).

There was also a significant two-way interaction between repetition and code-switching (β = −62.75, SE = 14.95, t = −4.20, p < .001). Repeated targets were produced with shorter duration than non-repeated targets in the stay condition (β = 30.52, SE = 7.29, t = 4.18, p < .001), but were produced with longer durations than non-repeated targets in the code-switch condition (β = −22.60, SE = 9.10, t = −2.49, p = .013). The main effect of repetition was not significant (β = 2.68, SE = 4.77, t = 0.56, p = .574).

For utterance proportion, there was a significant three-way interaction (β = −2.19, SE = 0.85, t = −2.57, p = .010) between repetition, code-switching, and response-dominance (see Fig. 4C). When responding in their non-dominant language, there was a significant interaction between repetition and code-switching (β = −2.86, SE = 0.70, t = −4.10, p < .001), in which repeated targets were produced with smaller utterance proportions than non-repeated targets in the stay condition (β = 1.81, SE = 0.51, t = 3.52, p < .001), but with larger utterance proportions than non-repeated targets in the switch condition (β = −1.53, SE = 0.57, t = −2.69, p = .007). When unbalanced bilinguals responded in their dominant language, the interaction between repetition and code-switching was not significant (β = −0.99, SE = 0.57, t = −1.75, p = .081).

There was also a significant three-way interaction between repetition, response-dominance, and participant type (β = −1.77, SE = 0.86, t = −2.06, p = .039). When responding in the dominant language, there was a significant interaction between repetition and participant type (β = 1.41, SE = 0.68, t = 2.09, p = .037). English-dominant bilinguals demonstrated a main effect of repetition in which repeated targets were produced with smaller utterance proportion compared to non-repeated targets (β = 1.64, SE = 0.48 t = 3.45, p < .001), while Korean-dominant bilinguals did not show a main effect (β = 0.23, SE = 0.48, t = 0.48, p = .635) of repetition (see Fig. 7A and B). When responding in the non-dominant language, the interaction between repetition and participant type was not significant (β = −0.75, SE = 0.71, t = −1.06, p = .291).

Utterance proportions in unbalanced bilinguals also showed a significant two-way interaction between repetition and code-switching (β = −1.77, SE = 0.43, t = −4.13, p < .001). Repeated targets were produced with smaller utterance proportions than non-repeated targets in the stay condition (β = 1.58, SE = 0.35, t = 4.47, p < .001), but not in the code-switch condition (β = −0.55, SE = 0.37, t = −1.49, p = .135). Finally, there was a significant main effect of repetition on utterance proportion (β = 0.55, SE = 0.23, t = 2.43, p = .015) in which repeated targets were produced with smaller utterance proportions than non-repeated targets. Given the interaction between repetition and participant type, the main effect of repetition was likely driven by English-dominant bilinguals.

Intensity

There was a significant interaction between repetition and code-switching (β = −0.58, SE = 0.25, t = −2.30, p = .021) in unbalanced bilinguals (see Fig. 5C). Repeated targets were produced with lower raw intensity than non-repeated targets in the stay condition (β = 0.47, SE = 0.17, t = 2.73, p = .006) but not in the code-switch condition (β = −0.11, SE = 0.20, t = −0.57, p = .569). The main effect of repetition was not significant (β = 0.21, SE = 0.13, t = 1.66, p = .097).

The means for relative intensity in unbalanced bilinguals are presented in Fig. 6C. For relative intensity, there was a significant interaction between repetition and code-switch (β = −1.82, SE = 0.51, t = −3.58, p < .001) in which repeated targets were produced with lower relative intensity than non-repeated targets in the stay condition (β = 1.38, SE = 0.46, t = 2.97, p = .003), but not in the code-switch condition (β = −0.59, SE = 0.43, t = −1.37, p = .171). The main effect of repetition was not significant for relative intensity (β = 0.42, SE = 0.30, t = 1.38, p = .167).

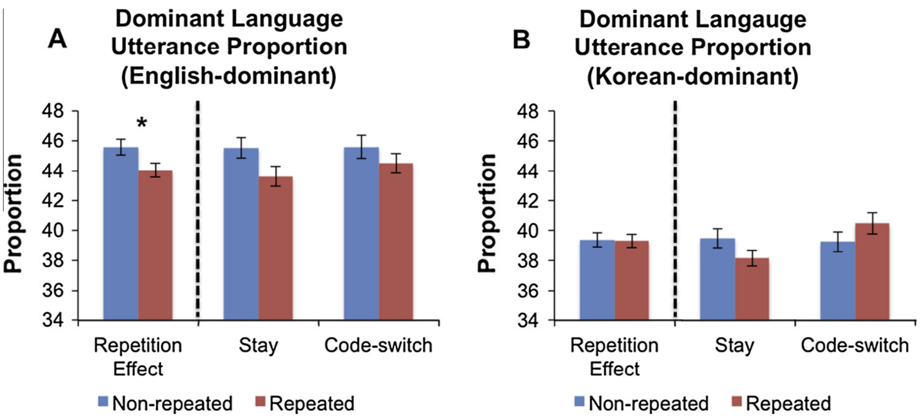

Fig. 7. Average utterance proportions in the dominant language for targets produced by English-dominant bilinguals (Panel A) and for targets produced by Korean-dominant bilinguals (Panel B). The left side of each chart depicts the main effect of repetition collapsed across Stay and Code-switch trials. Asterisks indicate significant effects (p < .05).

Discussion

When bilingual Korean–English speakers performed a task in which they repeatedly mentioned targets with and without a language switch, repeated targets were reduced when the language did not change, but were not reduced when the language changed. This pattern was seen for raw duration, utterance proportion, and relative intensity. For raw intensity, repetition led to reduction whether or not there was a language switch, signaling potential differences in how duration and intensity convey prominence in an utterance (see Lam & Watson, 2010; Watson et al., 2008).

We also saw different patterns of repetition reduction for balanced and unbalanced bilinguals. For raw duration and utterance proportion, balanced bilinguals demonstrated repetition reduction whether or not the word itself was repeated, suggesting that concept-level repetition can lead to prominence reduction even in the absence of word-level repetition. In contrast, unbalanced bilinguals did not show effects of concept-level repetition.

A significant three-way interaction between repetition, code-switching and language-balance for relative intensity suggests that balanced and unbalanced bilinguals also respond differently to word-level repetition. While unbalanced bilinguals demonstrated repetition reduction for word-level repetition, balanced bilinguals did not show repetition reduction for relative intensity. Conversely, the lack of a three-way interaction for raw duration or utterance proportion suggests that for duration, balanced bilinguals and unbalanced bilinguals may exhibit similar patterns of repetition reduction for word-level repetition. However, follow-up analyses indicated that word-level repetition only affects repetition reduction in unbalanced bilinguals.

Though unbalanced bilinguals demonstrated word-level repetition reduction in general, there were different patterns across the dominant vs. non-dominant language for raw duration and utterance proportion. While repeated targets produced in the non-dominant language were reduced when the language was also repeated, they were lengthened when there was a language switch; this pattern did not hold in the non-dominant language. For raw and relative intensity, unbalanced bilinguals reduced repeated targets in the same language, but not when the language changed. Unlike duration, intensity was unaffected by response language dominance. Moreover, Korean-dominant bilinguals and English-dominant bilinguals displayed slightly different patterns of repetition reduction for utterance proportion. When production was in their dominant language, English-dominant bilinguals exhibited repetition reduction for concept repetition, but Korean-dominant bilinguals did not. When responding in the non-dominant language, neither English-dominant nor Korean-dominant bilinguals showed any effects of concept repetition.

Locus of repetition reduction

The results of our study suggest that not *all* reduction can be attributed to concept level repetition. Because concepts are shared across languages (e.g., Costa, 2005; Kroll & Stewart, 1994), if repetition reduction were situated only at the concept level, then repetition reduction should be present whether or not the word itself was repeated. While the main effect of repetition for intensity was consistent with this prediction, the observed interaction between repetition and code-switching in the other three metrics suggests that repetition reduction must be at least partly influenced by word-level repetition. In addition, follow-up comparisons between balanced and unbalanced bilinguals indicated that the locus of repetition reduction is affected by the connection strength between words and concepts.

Although not all repetition reduction can be attributed to concept-level repetition, the results for balanced bilinguals suggest that concepts do play a role in repetition reduction. Even when the language, and thus the word, had changed, balanced bilinguals reduced duration for repeated targets. This suggests that repetition reduction *can* exist without word repetition. Given this pattern, it is possible that repetition reduction manifests through the repeated access of a particular concept. In this sense, prior activation caused the concept to be more accessible, leading to faster subsequent retrieval of the concept.

Nevertheless, the patterns of reduction in unbalanced bilinguals are most consistent with word-level repetition reduction. In support of word-mediated reduction, unbalanced bilinguals demonstrated repetition reduction for repeated targets in the stay trials (concept and word repetition), but not in the code-switch trials (concept repetition only). Furthermore, for measures of duration, when unbalanced bilinguals switched from the dominant language to the less dominant language in the concept repetition only condition, rather than being reduced in prominence, the repeated targets were instead produced with greater prominence (longer raw durations and larger utterance proportions) than non-repeated targets. This pattern may be indicative of a greater cost of switching from a word in the dominant language to a word in the non-dominant language (e.g., Kroll et al., 2008) when repeatedly mentioning the same target. These results suggest that repetition reduction is also influenced by the accessibility of the words used to describe a particular referent.

When data from balanced and unbalanced bilinguals are considered together, the pattern of results suggests that repetition reduction may be influenced by *both* concept and word repetition. Though repetition reduction may occur in the absence of word repetition in balanced bilinguals, unbalanced bilinguals demonstrated repetition reduction only in the presence of both concept and word repetition. One explanation for the different patterns in balanced vs. unbalanced bilinguals may be that repetition reduction is mediated by the link between the concept and the word (i.e., the step between determining the concept and retrieving the appropriate word). A number of theories suggest that concepts may activate multiple words so that words that are highly related to target words also receive some activation (Costa et al., 2000; Dell, 1986; Dell & O'Seaghdha, 1991; Levelt et al., 1999; Peterson & Savoy, 1998). In the case of translation equivalents, conceptual information is nearly identical. While this could lead to translation equivalents having similar levels of activation as target words for balanced bilinguals, concepts may activate words in each language to different degrees in unbalanced bilinguals because unbalanced bilinguals have stronger links between concepts and words in their dominant language than in their less dominant language (Kroll & Stewart, 1994). When a concept activates multiple words (as in balanced bilinguals), there may be repetition reduction without explicit word repetition because the non-selected words still receive some activation. If the concept preferentially activates a single word (as in unbalanced bilinguals), there may be no effect of concept repetition in the absence of word repetition because the non-selected words did not receive any activation. As a result, balanced bilinguals reduce repeated targets both with and without word repetition whereas unbalanced bilinguals only reduce repeated targets when there was word repetition.

Another possible explanation for our results is that repetition reduction exists for repeated concepts, but this effect was obscured because unbalanced bilinguals have difficulty inhibiting the previously-used word due to the recency and frequency of use biases (e.g., Brennan & Clark, 1996; Garrod & Anderson, 1987; Garrod & Doherty, 1994). Balanced bilinguals would not have these frequency biases because the words are balanced across the two languages (Costa et al., 2000; Gollan & Ferreira, 2009). The previously-used word may be a salient competitor leading to slower retrieval of the target word, which may offset any effect of repeated concepts. This explanation is consistent with the fact that when unbalanced bilinguals switched from the dominant language to the non-dominant language, repeated targets were actually produced with greater prominence rather than reduced prominence. Because unbalanced bilinguals require more effort to inhibit words in their dominant language than in their non-dominant language (Kroll et al., 2008), if production of the first utterance was in their dominant language, the target word from the first utterance may be more accessible than the word in the non-dominant language. According to accessibility theories of reduction (e.g., Bell et al., 2009; Kahn & Arnold, 2012; Lam & Watson, 2010), differences in the accessibility of words should lead to differences in prominence such that accessible words are produced with less prominence whereas less accessible words are produced with greater prominence.

Difficulty in suppressing a previous word may also explain the differences between Korean-dominant bilinguals and English-dominant bilinguals with respect to utterance proportion. Whereas both groups reduced repeated targets in the stay condition, in the code-switch condition, English-dominant bilinguals produced repeated targets with smaller utterance proportions if they were responding in their dominant language (i.e., English), while Korean-dominant bilinguals did not show a repetition by response-language interaction. Given that the study was conducted in an English-speaking country and context, English words may be more accessible than Korean words. When considered together with their already existing preference to use English, the English-dominant bilinguals should have less difficulty suppressing the Korean word for the English translation, which could allow for repetition reduction in the absence of word repetition.

Our results for balanced bilinguals differed from Monsell et al. (1992), for which word repetition led to reduction, but conceptual repetition did not. There are a few possible explanations for the discrepancy between their results and ours. First, while our balanced bilinguals showed an effect of concept repetition, our unbalanced bilinguals showed an effect that was similar to Monsell et al. (1992). For unbalanced bilinguals, repetition reduction typically occurred only when the language was the same across productions (i.e., word repetition). Monsell et al. (1992) presented no data on language balance among their bilinguals. It is possible that if they had separated their analysis by language balance, they may have shown conceptual repetition effects for balanced bilinguals. Second, the time scales of the two studies were different. In Monsell et al. (1992), concept repetition occurred over a large time scale and in a very different type of task across the two productions. In our study, the repeated target was mentioned in the immediately preceding sentence. This shorter time difference is better suited to a study of reference production because previous referring expressions are still available. Finally, unlike in Monsell et al. (1992), repeated targets in our manipulation were presented in the same visual context both within and across languages. Although speakers used two different words in the repeated-target code-switch condition, both words referred to the same object, and the object was visible on the screen between the two events. In Monsell et al. (1992), repetition primes came from sentence completions or definitions in a separate task. The change of both referent and context may have led different concepts to be activated across the two tasks because the meaning of a word changes depending upon its context (Olson, 1970).

Conclusions

In conclusion, our experiment suggests that repetition reduction is linked to repetition at both the concept level and the word level. Across a mixed group of bilingual speakers, participants reduced repeated targets only when the word itself was repeated, suggesting that repetition of concepts is not sufficient for repetition reduction. However, a more nuanced conclusion is reached when separating analyses based upon language balance. While unbalanced bilinguals showed only word-mediated repetition reduction, balanced bilinguals showed reduction whether or not the word itself was repeated. This suggests that concept repetition can affect repetition reduction in the absence of word repetition when strong links exist between concepts and words in both languages (as is the case for balanced bilinguals). We suggest that the connections between concepts and words within a speaker's language system determine whether or not repetition reduction can occur in the absence of word repetition.

Appendix A

Individual participant language profiles

Participant	Age of acquisition Korean	Age of acquisition English	Korean proficiency	English proficiency	Language balance
CP1	0	8	10	8.5	Korean
CP2	0	1	10	8	Korean
CP3	1	1	10	6	Korean
CP4	0	16	10	7.5	Korean
CP5	1	12	10	10	Balanced
CP6	1	1	9	7.5	Korean
CP7	0	10	10	8	Korean
CP8	1	10	10	9	Balanced
CP9	1	2	9	10	Balanced
CP10	0	4	10	8	Korean
CP11	0	10	10	10	Balanced
CP12	0	3	8.5	10	English
CP13	2	8	9.5	10	Balanced
CP14	2	4	7	8.5	English
CP15	0	10	10	8.5	Korean
CP16	0	4	9.5	5	Korean
CP17	0	7	10	7.5	Korean
CP18	0	0	8	8	Balanced
CP19	0	8	8.5	10	English
CP20	0	8	10	8.5	Korean
CP21	1	7	9	8	Balanced
CP22	0	5	10	9.5	Balanced
CP23	0	7	9	9.5	Balanced
CP24	0	7	10	8	Korean
CP25	0	10	9	8	Balanced
CP26	0	4	10	10	Balanced
CP27	0	3	9.5	8	Korean
CP28	2	1	9	10	Balanced
CP29	0	6	7.5	10	English
CP30	1	1	10	10	Balanced
CP31	0	10	9.5	8	Korean
CP32	0	2	10	10	Balanced
CP33	0	3	9	8.5	Balanced
CP34	0	6	8.5	9.5	English
CP35	0	5	8.5	10	English
CP36	1	3	9	10	Balanced
CP37	0	0	8	10	English
CP39	3	8	7.5	10	English
CP41	2	6	6.5	10	English
CP38	0	12	10	8.5	Korean
CP40	0	3	8	10	English
CP42	2	4	8.5	10	English
CP43	1	4	10	7	Korean
CP44	1	4	8	10	English
CP45	1	3	7.5	9	English
CP46	0	10	8.5	10	English
CP47	0	4	7	10	English
CP48	0	9	8.5	10	English

Appendix B: Analysis results tables

In this appendix, we present the full results tables for all fixed effects in each of our analyses on all participants, balanced bilinguals, and unbalanced bilinguals.

1. Results tables for analyses on all participants (models excluding language-balance).
2. Results tables for analyses on all participants (models including language-balance).
3. Results tables for analyses on balanced bilinguals.
4. Results tables for analyses on unbalanced bilinguals.

Results tables for analyses on all participants (models excluding language-balance)

1a. Raw duration (All Participants, model excluding language-balance).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	533.15	17.42	30.61	<1e−03
Repetition	9.46	4.42	2.13	.033
Codeswitch	13.84	3.93	3.52	<1e−03
Repetition:Codeswitch	−54.63	10.13	−5.39	<1e−03

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive.

1b. Utterance proportion (all participants, model excluding language-balance).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	44.67	0.87	51.26	<1e−03
Repetition	0.96	0.22	4.32	<1e−03
Codeswitch	0.90	0.18	4.90	<1e−03
Repetition:Codeswitch	−1.70	0.40	−4.26	<1e−03

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive.

1c. Raw intensity (All Participants, model excluding language-balance).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	62.27	0.67	92.37	<1e−03
Repetition	0.24	0.11	2.14	.032
Codeswitch	0.50	0.12	4.15	<1e−03
Repetition:Codeswitch	−0.30	0.26	−1.15	.250

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive.

1d. Relative intensity (All Participants, model excluding language-balance).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	5.80	0.45	13.00	<1e−03
Repetition	0.75	0.27	2.82	.005
Codeswitch	1.20	0.23	5.14	<1e−03
Repetition:Codeswitch	−1.09	0.52	−2.10	.036

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive.

Results tables for analyses on all participants (models including language-balance)

2a. Raw duration (all participants, model including language-balance).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	530.94	17.68	30.02	<1e−03
Repetition	8.77	4.37	2.00	.045
Codeswitch	13.55	3.93	3.45	<1e−03
Balance	−11.54	15.21	−0.76	.448
Repetition:Codeswitch	−52.90	9.55	−5.54	<1e−03
Repetition:Balance	17.61	6.85	2.57	.010
Codeswitch:Balance	14.56	7.05	2.06	.039
Repetition:Codeswitch:Balance	18.41	13.68	1.35	.178

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive. For the factor "Balance," the unbalanced bilingual level is coded negative while the balanced bilingual level is coded positive.

2b. Utterance proportion (All Participants, model including language-balance).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	44.45	0.88	50.50	<1e−03
Repetition	0.95	0.21	4.40	<1e−03
Codeswitch	0.84	0.17	4.88	<1e−03
Balance	−0.11	0.95	−0.12	.906
Repetition:Codeswitch	−1.56	0.37	−4.17	<1e−03
Repetition:Balance	0.99	0.38	2.61	.009
Codeswitch:Balance	0.63	0.37	1.70	.089
Repetition:Codeswitch:Balance	0.95	0.74	1.29	.197

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive. For the factor "Balance," the unbalanced bilingual level is coded negative while the balanced bilingual level is coded positive.

2c. Raw intensity (All Participants, model including language-balance).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	62.24	0.67	93.53	<1e−03
Repetition	0.24	0.11	2.16	.031
Codeswitch	0.50	0.12	4.14	<1e−03
Balance	2.27	1.39	1.62	.103
Repetition:Codeswitch	−0.29	0.21	−1.38	.162
Repetition:Balance	−0.06	0.23	−0.24	.807
Codeswitch:Balance	−0.36	0.25	−1.44	.150
Repetition:Codeswitch:Balance	0.74	0.45	1.63	.101

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive. For the factor "Balance," the unbalanced bilingual level is coded negative while the balanced bilingual level is coded positive.

2d. Relative intensity (All Participants, model including language-balance).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	5.78	0.45	12.96	<1e−03
Repetition	0.75	0.27	2.81	.005
Codeswitch	1.19	0.23	5.11	<1e−03

(*continued on next page*)

Results tables for analyses on all participants (models including language-balance) (continued)

	Estimate	Std. error	*t*-value	*p*
Balance	−0.49	0.79	−0.63	.530
Repetition:Codeswitch	−1.15	0.52	−2.21	.027
Repetition:Balance	−0.05	0.60	−0.08	.933
Codeswitch:Balance	−0.13	0.53	−0.24	.808
Repetition:Codeswitch:Balance	2.18	1.00	2.17	.030

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive. For the factor "Balance," the unbalanced bilingual level is coded negative while the balanced bilingual level is coded positive.

Results tables for analyses on balanced bilinguals

3a. Raw duration (Balanced Bilinguals).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	491.28	18.86	26.05	<1e−03
Repetition	29.10	5.82	5.00	<1e−03
Codeswitch	17.69	7.03	2.52	.012
Repetition:Codeswitch	−22.80	13.70	−1.66	.096

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive.

3b. Utterance proportion (Balanced Bilinguals).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	43.51	1.08	40.45	<1e−03
Repetition	1.53	0.29	5.28	<1e−03
Codeswitch	0.80	0.33	2.44	.015
Repetition:Codeswitch	−0.64	0.59	−1.08	.281

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive.

3c. Raw intensity (Balanced Bilinguals).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	62.90	1.11	56.70	<1e−03
Repetition	0.28	0.27	1.04	.299
Codeswitch	0.21	0.21	0.99	.320
Repetition:Codeswitch	0.13	0.44	0.29	.772

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive.

3d. Relative intensity (balanced bilinguals).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	4.44	0.66	6.70	<1e−03
Repetition	0.37	0.61	0.60	.547
Codeswitch	0.87	0.40	2.18	.029
Repetition:Codeswitch	0.45	0.91	0.49	.622

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive.

Results tables for analyses on unbalanced bilinguals

4a. Raw duration (unbalanced bilinguals).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	531.76	19.46	27.32	<1e−03
Repetition	2.68	4.77	0.56	.574
Codeswitch	8.54	4.91	1.74	.082
DomLang	24.11	11.38	2.12	.034
PartType	10.83	20.80	0.52	.603
Repetition:Codeswitch	−62.75	14.95	−4.20	<1e−03
Repetition:DomLang	−10.23	9.55	−1.07	.284
Codeswitch:DomLang	4.11	10.03	0.41	.682
Repetition:PartType	7.49	8.24	0.91	.363
Codeswitch:PartType	0.45	8.96	0.05	.960
DomLang:PartType	−3.66	69.47	−0.05	.958
Repetition:Codeswitch:DomLang	−45.42	15.47	−2.94	.003
Repetition:Codeswitch:PartType	−15.51	20.49	−0.76	.449
Repetition:DomLang:PartType	−7.70	21.38	−0.36	.719
Codeswitch:DomLang:PartType	43.14	21.58	2.00	.046
Repetition:Codeswitch:DomLang:PartType	1.41	53.42	0.03	.979

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive. For the factor "DomLang", the dominant language level is coded negative while the non-dominant language level is coded positive. For the factor "PartType," the Korean-dominant level is coded negative while the English-dominant level is coded positive.

4b. Utterance proportion (unbalanced bilinguals).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	44.38	0.85	52.04	<1e−03
Repetition	0.55	0.23	2.43	.015
Codeswitch	0.81	0.22	3.68	.000
DomLang	0.79	0.79	1.00	.318
PartType	−1.76	1.05	−1.67	.095
Repetition:Codeswitch	−1.77	0.43	−4.13	<1e−03
Repetition:DomLang	−0.52	0.42	−1.22	.224
Codeswitch:DomLang	0.02	0.43	0.06	.955
Repetition:PartType	0.27	0.45	0.61	.543
Codeswitch:PartType	0.14	0.43	0.33	.743
DomLang:PartType	−20.16	3.10	−6.50	<1e−03
Repetition:Codeswitch:DomLang	−2.19	0.85	−2.57	.010
Repetition:Codeswitch:PartType	−0.54	0.85	−0.63	.530
Repetition:DomLang:PartType	−1.77	0.86	−2.06	.039
Codeswitch:DomLang:PartType	1.49	0.88	1.70	.090
Repetition:Codeswitch:DomLang:PartType	−1.61	1.72	−0.94	.348

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive. For the factor "DomLang", the dominant language level is coded negative while the non-dominant language level is coded positive. For the factor "PartType," the Korean-dominant level is coded negative while the English-dominant level is coded positive.

4c. Raw intensity (unbalanced bilinguals).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	61.54	0.77	80.35	<1e−03
Repetition	0.21	0.13	1.66	.097
Codeswitch	0.56	0.17	3.30	.001
DomLang	0.23	0.15	1.49	.136
PartType	−0.18	1.52	−0.12	.908
Repetition:Codeswitch	−0.58	0.25	−2.30	.021
Repetition:DomLang	−0.06	0.25	−0.25	.805
Codeswitch:DomLang	0.30	0.25	1.19	.236
Repetition:PartType	0.16	0.25	0.65	.519
Codeswitch:PartType	0.18	0.30	0.61	.543
DomLang:PartType	−0.84	0.52	−1.63	.104
Repetition:Codeswitch:DomLang	0.21	0.50	0.42	.671
Repetition:Codeswitch:PartType	0.43	0.50	0.85	.394
Repetition:DomLang:PartType	0.71	0.50	1.42	.156
Codeswitch:DomLang:PartType	−0.49	0.59	−0.82	.410
Repetition:Codeswitch:DomLang:PartType	−1.44	1.01	−1.43	.153

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive. For the factor "DomLang", the dominant language level is coded negative while the non-dominant language level is coded positive. For the factor "PartType," the Korean-dominant level is coded negative while the English-dominant level is coded positive.

4d. Relative intensity (unbalanced bilinguals).

	Estimate	Std. error	*t*-value	*p*
(Intercept)	7.95	0.62	12.89	<1e−03
Repetition	0.42	0.30	1.38	.167
Codeswitch	0.94	0.34	2.77	.006
DomLang	1.56	0.79	1.97	.049
PartType	0.07	1.17	0.06	.954
Repetition:Codeswitch	−1.82	0.51	−3.58	<1e−03
Repetition:DomLang	0.27	0.50	0.53	.594
Codeswitch:DomLang	0.91	0.50	1.81	.070
Repetition:PartType	0.68	0.60	1.13	.260
Codeswitch:PartType	−0.55	0.66	−0.83	.405
DomLang:PartType	−10.19	1.77	−5.76	<1e−03
Repetition:Codeswitch:DomLang	0.81	1.01	0.80	.423
Repetition:Codeswitch:PartType	0.19	1.01	0.19	.851
Repetition:DomLang:PartType	0.98	1.01	0.97	.331
Codeswitch:DomLang:PartType	−1.52	1.05	−1.44	.150
Repetition:Codeswitch:DomLang:PartType	−1.42	2.03	−0.70	.483

Note: For the factor "Repetition," the repeated level is coded negative while the non-repeated level is coded positive. For the factor "Codeswitch," the stay level is coded negative while the code-switch level is coded positive. For the factor "DomLang", the dominant language level is coded negative while the non-dominant language level is coded positive. For the factor "PartType," the Korean-dominant level is coded negative while the English-dominant level is coded positive.

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