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More use almost always a means a smaller frequency effect: Aging, bilingualism, and the weaker links hypothesis

Tamar H. Gollan[1,2], **Rosa I. Montoya**[1,2], **Cynthia Cera**[1], and **Tiffany C. Sandoval**[1,3]

1 *University of California San Diego, Department of Psychiatry*

2 *Alzheimer's Disease Research Center, UCSD*

3 *San Diego State University, Department of Psychology*

Abstract

The "weaker links" hypothesis proposes that bilinguals are disadvantaged relative to monolinguals on speaking tasks because they divide frequency-of-use between two languages. To test this proposal we contrasted the effects of increased word use associated with monolingualism, language dominance, and increased age on picture naming times. In two experiments, younger and older bilinguals and monolinguals named pictures with high- or low-frequency names in English and (if bilingual) also in Spanish. In Experiment 1, slowing related to bilingualism and language dominance was greater for producing low- than high-frequency names. In Experiment 2, slowing related to aging was greater for producing low-frequency names in the dominant language, but when speaking the nondominant language, increased age attenuated frequency effects and age-related slowing was limited exclusively to high-frequency names. These results challenge competition based accounts of bilingual disadvantages in language production, and illustrate how between-group processing differences may emerge from cognitive mechanisms general to all speakers.

Keywords

Spanish; aging; bilingualism; frequency effect; picture naming

In trying to find the words we need to express our thoughts, it is much easier to retrieve and say the names of things that we talk about very often (e.g., *cup*s) than the names of things that we don't talk about as often (e.g., *carafes*). Although nobody will argue with this point, there has been some debate with respect to the precise mechanism of frequency effects in language processing models (e.g., Murray & Forster, 2004), and whether frequency itself – or one of many variables that are correlated with frequency (e.g., AoA, length) – determines what makes frequently used words easier to access than infrequently used words (e.g., Gernsbacher, 1984). People who regularly speak more than one language provide a unique opportunity to investigate the relationship between frequency of use and lexical accessibility.

Bilinguals know roughly twice as many words as monolinguals (assuming bilinguals know a word in each language for most lexicalized concepts). Despite the approximately doubled load, bilinguals seem to effortlessly use the right word in the right context, and can even switch back

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Please address editorial comments to: Tamar H. Gollan, Department of Psychiatry, University of California, San Diego, 9500 Gilman Drive, 0949, La Jolla, CA 92093-0949, fax: 858-622-1017, e-mail: tgollan@ucsd.edu.

and forth between languages with little obvious cost. However, evidence suggests that maintaining more than one language in a single cognitive system introduces some subtle but significant processing costs. When compared to their monolingual peers, bilinguals have more tip-of-the-tongue or TOT retrieval failures (Gollan & Acenas, 2004; Gollan, Bonanni, & Montoya, 2005; Gollan & Silverberg, 2001, but see Gollan & Brown, 2006), have reduced category fluency (Gollan, Montoya, & Werner, 2002; Portocarrero, Burright, & Donovick, 2007; Rosselli et al., 2000), name pictures more slowly (Gollan, Montoya, Fennema-Notestine, & Morris, 2005), and name fewer pictures correctly on standardized naming tests such as the Boston Naming Test (Kohnert, Hernandez, & Bates, 1998; Roberts, Garcia, Desrochers, & Hernandez, 2002; Gollan, Fennema-Notestine, Montoya, & Jernigan, 2007). Importantly, bilingual naming disadvantages were found even when bilinguals were tested exclusively in their dominant language (e.g., Gollan & Acenas, 2004; Gollan, Montoya et al., 2005), and more recently in bilinguals who are dominant in their first-learned language (Ivanova & Costa, in press; many of the bilinguals in the studies by Gollan et al., were dominant in their second-learned language).

Though it seems to be robust the bilingual disadvantage is not generalized. Although bilinguals had more TOTs than monolinguals when trying to retrieve noncognates (i.e., phonologically dissimilar translations such as *muzzle* and its Spanish equivalent *bozal*), they had the same number of TOTs as monolinguals when the picture names were cognates (Gollan & Acenas, 2004) which are translation equivalents with similar forms (e.g., *pirámide* is Spanish for *pyramid*). In one case, there was no bilingual disadvantage on one of the most difficult production tasks. Bilinguals and monolinguals had significantly fewer TOTs (Experiment 1, Gollan, Bonanni, et al., 2005), or similar numbers of TOTs (Experiment 2, Gollan, Bonanni, et al., 2005), for proper names even though proper name retrieval was relatively more difficult than object name retrieval for monolinguals. Bilinguals may be effectively monolingual for proper names which seldom differ between languages (e.g., *Golda Meir* is the same in Hebrew and in English). In addition, slowing related to bilingualism is limited to language processing tasks. For example, bilinguals named pictures more slowly than monolinguals, but classified the same pictures as “human-made” or “natural” as quickly as monolinguals suggesting that the bilingual disadvantage arises during or after (but not before) lexical selection (Gollan, Montoya, et al., 2005). Finally, bilinguals display substantially faster processing speed relative to monolinguals on some non-linguistic tasks (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004).

To explain why bilinguals are at a disadvantage relative to monolinguals on some production tasks Gollan and colleagues proposed the “weaker links” hypothesis which assumes a very indirect effect of bilingualism on lexical retrieval (Gollan & Silverberg, 2001; Gollan et al., 2002; Gollan & Acenas, 2004; Gollan, Bonanni, et al., 2005; Gollan, Montoya, Fennema-Notestine, & Morris, 2005; see also Mägiste, 1979; Ransdell & Fischler, 1987). Because bilinguals speak two languages, and because they can only speak one language at a time (for an exception see Emmorey, Borinstein, Thompson, & Gollan, in press), bilinguals necessarily speak each language less often than do monolinguals. Because bilinguals use words in each language less frequently than do monolinguals, lexical representations (in both languages) in the bilingual system will have accumulated less practice overall, relative to lexical representations in the monolingual system. Over time, bilingual patterns of language use should lead to weaker links between semantics and phonology in each lexical system, relative to monolinguals, because words that are produced more often are easier to produce. In this way, the weaker links hypothesis draws an analogy between patterns of language use, bilingualism, and frequency effects whereby increased use leads to improved lexical accessibility. A unique aspect of the weaker links hypothesis is that it assigns the consequences of bilingualism to the same mechanism that influences accessibility in all speakers (i.e., frequency) rather than to mechanisms more specific to the bilingual circumstance. The weaker links should be “weaker” specifically at the point in the production system where frequency effects are strongest in all speakers. As such, as we discuss below, predictions about how bilinguals should differ from monolinguals within the weaker links framework depend entirely on the mechanism of frequency effects in models of language processing.

A more obvious account of why bilingualism affects language production attributes the bilingual disadvantage to competition between translation equivalents. On this view, bilinguals face unusually fierce competition each time they speak because, for any given concept, they know two words (translations) that fit their intended meaning very well, whereas monolinguals typically know just one. An exception that may lead monolinguals to function more like bilinguals is where synonyms exist within a single language (e.g., *sofa* and *couch*), and synonyms in fact pose special problems in monolingual production (Jescheniak & Schriefers, 1998; Peterson & Savoy, 1998). The notion that bilinguals must manage between-language interference fits well with an emerging consensus in the literature on bilingual language production that concepts automatically activate lexical representations in both languages (Green, 1998; Hermans, Bongaerts, de Bot, & Schreuder, 1998; Lee & Williams, 2001; Poulisse, 1997; for reviews see Costa, 2005; La Heij, 2005), even when the task requires bilinguals to speak in just one language (Colomé, 2001; Costa, Caramazza, & Sebastián-Galles, 2000; Gollan & Acenas, 2004). The assumption of between language interference is also needed to explain the various bilingual processing advantages over monolinguals in ability to resolve response conflict in non-linguistic tasks (for reviews see Bialystok, 2005; Bialystok & Feng, in press).

Importantly, the weaker links and interference hypotheses are not mutually exclusive; both mechanisms may be used simultaneously to explain different types of bilingual effects on language processing. The question must then be framed as which mechanism is relatively more effective for explaining bilingual performance in a given task or comparison. In this regard, the weaker links account is especially important for explaining why the size of the bilingual disadvantage is bigger for words that bilinguals tend to know in just one language both in terms of picture naming times (Gollan, Montoya, et al., 2005), and TOT rates (Gollan & Acenas, 2004). Because bilinguals are effectively monolingual for words that they know in just one language, it would be difficult (if not impossible) to explain these results with an interference mechanism (unknown words obviously cannot compete for selection). In addition, the weaker links notion is more powerful than interference for explaining why bilinguals are disadvantaged even for speaking in their dominant language given that there is relatively little evidence that the less-dominant language can interfere with dominant language production. In some studies, L2 (the less-dominant language) interfered with L1 (the dominant language) only after L2 was first activated by a task exclusively in L2 (Jared & Kroll, 2001). Similarly, language mixing slows L1 production dramatically, but has relatively little effect on L2, suggesting that L2 is otherwise not highly active when bilinguals speak in L1 (see review in Kroll, Bobb, & Wodniecka, 2006).

In the current investigation we provide a direct test of the weaker links hypothesis, and constrain the interference account, by examining the nature of the frequency effect in bilinguals versus monolinguals (in Experiment 1), in the dominant and nondominant languages (in Experiments 1 and 2), and by considering how bilingual effects, language dominance effects, and frequency effects may change with increased age (in Experiment 2). Because of its explicit reliance frequency of use, the weaker links hypothesis predicts that the bilingual disadvantage should be modulated by word frequency. In contrast, depending on the locus of competition between languages, and the locus of the frequency effect in language production, the interference account leaves open that the possibility that bilingual disadvantage will not be modulated by word frequency, or predicts that it should be modulated by frequency but (as outlined below) in the opposite direction as the weaker links account. In addition to constraining models of bilingualism, the current study addresses general questions concerning the relationship between frequency of use and lexical access in young and aging adults.

One study that seems to support the idea that the bilingual disadvantage will be modulated by frequency was based on the analogy between bilingualism, frequency, and repetition. In this study, the bilingual disadvantage became smaller with three repetitions (in Experiment 1) and was no longer significant after five repeated naming trials (Experiment 2; Gollan, Montoya, et al., 2005). Because some studies of monolingual picture naming showed that frequency effects become smaller with repetition (Griffin & Bock, 1998; Oldfield & Wingfield, 1965; for similar results see Forster & Davis, 1984; Scarborough et al., 1977), this study supports the weaker links account by suggesting that repetition gives bilinguals a chance to “catch up” to monolinguals in terms of degree of use. However, it is not clear to what extent repetition in the context of an experiment is analogous to increased use over time (Griffin, 2002; Murray & Forster, 2004; see discussion in Gollan, Montoya, et al., 2005), and some have found frequency effects to be remarkably stable in magnitude over several or many repetitions (Levelt, Roelofs, & Meyer, 1999; Navarrete, Basagni, Alario, & Costa, 2006).

A more direct test of the weaker links hypothesis can be obtained by directly manipulating word-frequency in the bilingual to monolingual comparison. To explain frequency effects, many models of language production (e.g., Caramazza, 1997; Dell, 1986, 1990, Dell et al., 1997; Griffin & Bock, 1998; Levelt, et al., 1999), and models of language comprehension whether monolingual (e.g., McClelland & Rumelhart, 1981; Morton, 1970; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1990) or bilingual (Dijkstra & Van Heuven, 2002), make the following, or very similar, assumptions: (a) lexical representations accumulate baseline levels of activation with increased use, (b) baseline levels of activation are promoted upwards with increased use as a proportion of their distance from threshold, (c) selection occurs when activation levels reach threshold. Below we refer to these assumptions as *the activation hypothesis*[1]. The second assumption is particularly important in the current context because it places a ceiling effect on baseline activation levels after which additional use no longer exerts substantial changes.

The ceiling on the degree to which increased use leads to increased lexical accessibility predicts that low-frequency words should be more affected by differences in degree-of-use than high-frequency words, and this provides the basis for making several predictions about how bilingualism, aging, and frequency should interact to affect language production. These are: (a) because bilinguals have used words in each language less often than monolinguals, bilinguals should show larger frequency effects than monolinguals (this is a prediction of the weaker links hypothesis), (b) because bilinguals use the nondominant language less often than the dominant language, frequency effects should be larger in the nondominant than in the dominant language, and (c) because younger adults have been speaking for less time than older adults, younger adults should show larger frequency effects than older adults (e.g., Tainturier, Tremblay, & Lecours, 1989; Murray & Forster, 2004) after controlling for age-related slowing (e.g., Cerella, 1985; Faust, Balota, Spieler, & Ferraro, 1999; Myerson, Hale, Wagstaff, Poon, & Smith,1990; Salthouse, 1996). Finally, (d) because increased age should allow bilinguals more time to “catch up” with monolinguals the bilingual disadvantage should become smaller as participants age. This modulation of bilingual effects by age also makes sense intuitively because it should be easier to learn twice as much (i.e., two languages) if you have more time to do it.

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[1] In some models (e.g., Plaut et al., 1996), frequency is considered a product of learning and so connection strength (rather than baseline activations of lexical units) is affected by frequency. Because such models use error-based learning, as they learn more about a specific item (e.g., as words become higher frequency), weight changes become smaller; this effectively imposes a ‘ceiling effect’ on performance, just as with baseline levels of activation in activation-based accounts. Because of this basic similarity between these types of models, we collapse their explanations for frequency effects under the term *activation hypothesis.*

Table 1 reports the output of a simple model that incorporates the basic assumptions of the activation hypothesis and illustrates the predictions just outlined. The model was created by arbitrarily assigning selection threshold to the value of 6, and by adjusting baseline activation levels upwards for increased frequency of use, and downwards for decreased use, as a proportion of distance from threshold to create a ceiling effect on baseline activation levels. As such, monolinguals are at higher baseline for each word than bilinguals, and words in the dominant language are at a higher baseline than words in the nondominant language (e.g., Dijkstra & Van Heuven, 2002;Hermans et al., 1998;Francis, Augustini, & Saenz, 2003). In addition, even though older adults generally name pictures slightly more slowly than young adults (for a review see Griffin & Spieler, 2006), older adults have higher baseline activation levels because age related slowing presumably reflects generalized slowing that originates from outside the language production system (e.g., Salthouse, 1996). In this model, bilinguals show bigger frequency effects than monolinguals (with frequency differences in activation of 4.20 versus 4.00), frequency effects are bigger in the nondominant than in the dominant language (4.41 versus 4.21), the size of the bilingual effect is bigger in young than in older adults (4.2 − 4.0 = 0.20 in young adults compared with 3.25 − 3.10 = 0.15 in older adults), and young adults show bigger frequency effects than older adults (4.00 versus 3.10 in monolinguals and 4.20 versus 3.25 in bilinguals). A different way of stating the same predictions is to say that low-frequency words show a bigger bilingual disadvantage (e.g., *glass* shows a 0.05 sized bilingual effect but *container* shows a difference of 0.25 between groups), bigger language dominance effects, and bigger age effects than high-frequency words.

A different set of predictions can be derived by assuming that the bilingual disadvantage in language production should be attributed to competition between translation equivalents. It should first be noted, that although there is agreement that dual-language activation seems to be constant (i.e., it is not possible to “turn a language off”) there is debate as to whether dual-language activation produces interference. Some researchers of bilingualism argue that lexical representations compete for activation between languages (e.g., Green, 1998; Hermans, et al., 1998; Hermans, 2004; Lee & Williams, 2001), but others argue that there is no direct competition for selection between languages (Costa, Miozzo, & Caramazza, 1999; Finkbeiner, Gollan, & Caramazza, 2006). As a way of reconciling both views, some have suggested that the bilingual production system can be language selective in some tasks, but that there is between-language competition in other tasks (Kroll, et al., 2006).

To explain the bilingual disadvantage using a competition account it is first necessary to assume that semantically related candidates compete for selection in language production (e.g., Cutting & Ferreira, 1999; Harley, 1993; Howard, Nickels, Coltheart, Cole-Virtue, 2006; Levelt et al., 1999; Lupker, 1979; Starreveld & La Heij, 1996; Stemberger, 1985; Wheeldon & Monsell, 1994), and then it is also necessary to assume that the nondominant language can compete to a sufficiently large extent that it delays production of the dominant language even during language-selective tasks. The interference account then predicts that the bilingual disadvantage should be modulated by frequency only if frequency effects arise at the same locus as between-language competition. There has been some debate in the literature regarding the locus of the frequency effect in models of language production (for a similar debate in research on word recognition see Balota & Chumbley, 1985 for a similar debate in research on word recognition see Balota & Chumbley, 1990; Savage, Bradley, & Forster, 1990). Some have argued that frequency effects arise during phonological encoding, but that frequency specifically does not influence lexical selection at the point where there is competition between semantically related candidates (Harley & Bown, 1998; Jescheniak & Levelt, 1994; Levelt, et al., 1999; Santesteban, Costa, Pontin, & Navarrete, 2006). Because frequency effects arise in these accounts after competition has already been resolved, these models would predict no modulation of the bilingual disadvantage by frequency (i.e., the bilingual disadvantage should be the same for retrieving low- and high-frequency words). Here we assume there is no competition between languages at the phonological level (e.g., Hermans et al., 1998; but see Colomé, 2001), because phonological overlap produces facilitation both in bilingual (e.g., Costa et al., 2000; Gollan & Acenas, 2004) and in monolingual production (Harley & Bown, 1998; Vitevitch, 2002).

An alternative view is that frequency affects lexical selection at the point where multiple semantically related candidates are active (e.g., Alario, Costa, & Caramazza, 2002; Bates, et al., 2003; Caramazza, Costa, Miozzo, & Bi, 2001; Dell & Reich, 1981; Dell, 1990; Griffin & Bock, 1998; Navarrete, et al., 2006). Frequency should also affect lexical selection in any model that allows feedback from the phonological level back up to the point of lexical selection (e.g., Cutting & Ferreira, 1999; Dell, 1986, 1990, 1997; Ferreira & Griffin, 2003, MacKay, 1982; see review in Rapp & Goldrick, 2000). Like the weaker links account, such models would predict that the bilingual disadvantage should be modulated by frequency (if translations compete for selection). The precise nature of the expected interactions is difficult to predict without making explicit assumptions about the nature of competition for selection. However, if we consider that bilinguals may effectively be “more bilingual” for high-frequency words, and assume that low-frequency words in the less dominant language may be particularly unlikely to compete with dominant language production, then between-language competition should affect the retrieval of high-frequency words relatively more than the retrieval of low-frequency words (the opposite prediction of the weaker links account). Finally, the interference account predicts that the size of the bilingual disadvantage should increase with increased age because older adults may be less able to control interference between-languages (Hernandez & Kohnert, 1999), and because aging may reduce the ability to control interference in language processing tasks (Connelly, Hasher, & Zacks, 1991; Logan & Balota, 2003; Spieler, Balota, & Faust, 1996; Taylor & Burke, 2002, Experiment 1; Zachs & Hasher, 1994) particularly when pictures with low-frequency names must be produced (Spieler & Griffin, 2006).

To test these predictions we asked whether the bilingual disadvantage, language dominance effects, and aging effects are modulated by word frequency. In terms of providing evidence for or against weaker links versus interference, only the weaker links hypothesis is very clearly tied to the prediction that bilinguals should show a bigger frequency effect than monolinguals. However, the other predictions are of interest because they provide an additional index of the relationship between lexical accessibility and frequency of use over time and so will constrain models of bilingualism, cognitive aging, and language production.

Experiment 1

In Experiment 1 we compared English speaking monolinguals with English-dominant Spanish-English bilinguals on picture naming times in English. In addition, within the bilingual group we also compared picture naming times in Spanish to naming times in English. We assumed that the bilinguals tested used English less often than monolinguals, and that bilinguals used Spanish less often than English, and therefore predicted that bilinguals should show bigger frequency effects than monolinguals, and that frequency effects should be larger in Spanish than in English (within the bilingual group).

To increase the generalizability of our findings (particularly concerning the previously observed bilingual disadvantages in picture naming) we did not restrict our frequency manipulation to materials that are strictly matched for the many variables that are correlated with frequency (see Cutler, 1981, Spieler & Balota, 2000; Juhasz, 2005 for arguments that it is nearly impossible to control for all variables potentially confounded with frequency, and Forster, 2000 for a discussion of experimenter bias effects in fully factorial designs). Note that the concern about potentially confounding variables is limited in the current study because picture naming limits the comparison of high- and low-frequency items to concrete names, and to the extent that confounds do exist these would be the same for bilinguals and monolinguals.

However, for both bilingual effects and language dominance effects, we considered the effects of two possible confounding variables in our analyses below with a particular focus on Age-of-Acquisition or AoA effects in the Discussion section.

High-frequency words tend to be learned at an early age whereas low-frequency words tend to be learned at a later age, and there has been considerable debate as to whether frequency or AoA (or both) determine lexical access time. The consensus emerging from these studies appears to be that both variables exert independent effects in a variety of tasks including lexical decision, reading aloud, and picture naming (e.g., Barry, Morrison, & Ellis, 1997; Ghyselinck, Lewis, & Brysbaert, 2004; Stadthagen-Gonzalez, Bowers, & Damian, 2004). Across studies AoA effects appear to be robust in picture naming (Lambon Ralph, & Ehsan, 2006; Meschyan & Hernandez, 2002 as predicted by Zevin & Seidenberg, 2002) whereas frequency effects are more robust in lexical decision. Importantly for the weaker links notion, there is agreement that AoA is unlikely to replace frequency as a predictor of picture naming times particularly for production of relatively late-acquired words (Barry, Hirsch, Johnston, & Williams, 2001).

Method

Participants

Fifty-seven English-speaking monolinguals and 73 Spanish-English bilinguals who were undergraduates at UCSD participated in the experiment for course credit. The bilinguals learned both languages at home at an early age, and monolinguals had no extended immersion experience, but had some (usually classroom based) exposure to a second language. The majority (n = 57) of the bilinguals reported being English-dominant or speaking English and Spanish equally well in a language history questionnaire. The remaining bilinguals (n = 16) reported being Spanish-dominant, and we excluded their data from analysis because bilinguals who remain Spanish-dominant despite being immersed in an English-dominant environment (UCSD) are different in a number of ways from the English-dominant bilinguals. First, they tended to acquire English at a later age and with greater variability in age-of-acquisition than the English-dominant bilinguals. Second, these “Spanish-dominant” participants on average rated themselves as being English-dominant for some modalities (e.g., reading); and a majority (11/16) reported only a slight tendency (a difference of 1 on the 7 point proficiency scale) towards Spanish dominance. In addition, the Spanish-dominant reported using English more than Spanish during daily use. Finally, the relatively small number of Spanish-dominant participants available (only 16) made it impossible to consider the possible effects of testing order on this subset of bilinguals.

Table 2 shows participant characteristics obtained from the language questionnaire. Monolinguals and bilinguals did not differ significantly in average age ($F < 1$) or years of education $F1(1,112) = 2.20$, $MSE = 2.49$, $\eta_p^2 = .02$, $p = .14$, but bilinguals reported using English less often than monolinguals on a daily basis, were exposed to English at a later age than monolinguals, were exposed to a non-English language (Spanish for all bilinguals) at an earlier age than monolinguals, were able to translate (see Procedure) more words into another language than monolinguals, and bilinguals also rated their ability to speak another language as higher than monolinguals (these differences were significant at the $p < .01$ level). In addition, bilinguals rated their ability to speak English significantly lower than monolinguals $F1(1,111) = 5.89$, $MSE = .12$, $\eta_p^2 = .05$, $p = .02$ (this result resembles those reported in other studies; e.g., Gollan & Acenas, 2004, Experiment 2, Gollan, Bonanni et al., 2005;Gollan, Montoya, et al., 2005;Gollan, et al., 2002; Note that the degrees of freedom for this comparison was 111 because of one monolingual who failed to provide a rating for spoken English).

Materials

We selected 132 black and white line-drawn pictures from Snodgrass and Vanderwart (1980) and other sources. Sixty items were from Griffin and Bock (1998), of which five had cognate names (translation equivalents that are similar in form). (Note that Griffin and Bock matched 30 high and 30 low-frequency items for length in phonemes, initial phoneme, and picture stimuli were matched for name agreement and object decision latencies). None of the other pictures were cognates. We used pseudo-random assignment to divide the materials into three frequency-matched lists each with 22 pictures with high-frequency and 22 with low-frequency English names. Table 3 shows the picture name characteristics. In all three lists, high- and low-frequency names differed significantly in mean English spoken noun frequency (all ps $< .01$) obtained from CELEX (Baayen, Piepenbrock, & Gulikers, 1995). For completeness we report the frequencies of the Spanish names (see Table 3) which we obtained from the LEXESP database (Sebastián-Gallés, Martí, Cuetos, & Carreiras, 2000) using Buscapalabras (Davis & Perea, 2005); these were highly correlated with the English frequencies ($r = .80$, $p < .01$). We used the English frequency values in the regression analyses reported below. The picture names are listed in the Appendix.

Across the lists, high-frequency words were between 1.0–1.3 phonemes longer than low-frequency words (see Table 3) in English (p values ranging from .04 to <.01), and high-frequency words were between 0.9–1.3 phonemes longer than low-frequency words in Spanish (p values ranging from .10 to .01). In addition, Spanish names were 1.6 (SD=1.8) longer than English names on average, but length differences between language did not interact with list number or frequency category (all Fs<1.3, ps $> .32$).

Procedure

Pictures were presented using PsyScope 1.2.5 (Cohen, MacWhinney, Flatt, & Provost, 1993) on a Macintosh computer with a 17-inch color monitor. Naming times were recorded using headset microphones connected to tape recorders and PsyScope response boxes. An experimenter recorded naming and voice-key accuracy online and later verified coding against the recordings. Each trial began with a 500 ms presentation of a central fixation point (‘+’) that was immediately replaced by the picture. Participants initiated each trial by pressing the space bar. The picture disappeared when the voice-key triggered (or with a 3-second deadline), and was replaced by minus sign which remained on the screen until the participant pressed the space-bar to initiate the next trial.

Instructions were to name pictures “as quickly as you can without making mistakes.” Bilinguals named pictures in each list in English only, or Spanish only, or using either-language based on whichever language came to mind first. The either-language condition was included as a part of a separate study on voluntary language-switching, and between subjects the bilinguals named pictures in each of the conditions first (as opposed to second or third) to make it possible to consider testing order effects. Lists were assigned to one of the 3 different conditions counterbalanced across subjects, with condition order counterbalanced across subjects. Monolinguals named pictures in lists 1–3 in English only. Thus, each participant saw each picture only once; monolinguals named all 132 pictures in English only, and bilinguals named 44 pictures in English, 44 in Spanish, and 44 in either language using whichever language they chose on each trial. In addition, roughly mid-way through the study we changed from the fixed to random order as a design improvement. Within each list pictures were presented in a fixed-random order for 29 bilinguals and 29 monolinguals, and in a different random order for an additional 28 bilinguals and 28 monolinguals. As an objective measure of bilingualism, after completing the picture naming portion, participants translated in writing the names of the pictures they had named in English (and in the “either” condition) into Spanish, and the names of the pictures they had named in Spanish into English. Monolinguals translated as many names as they could into some other language (mostly Spanish for 51 of the 57 monolinguals).

Results

To trim outliers, we discarded all reaction times (RTs) below 250 or above 5000 ms; pictures disappeared after 3 seconds, but responses produced after the 3-second deadline were recorded, and we included correct naming times up to 5000 ms in our analyses. The cutoffs trimmed 2.2% or less of the correct RT data points for all participants; for monolinguals $M = 0.2\%$; $SD = 0.4\%$, for bilinguals in English $M = 0.5\%$; $SD = 1.2\%$, and for bilinguals in Spanish $M = 2.2\%$; $SD = 4.2\%$. Note that we obtained the same pattern of results as reported below (except that the mean RTs and the size of frequency effects were smaller) when we repeated our analyses after also trimming all RTs that were more or less than 2.0 *SD*s above or below each participant's mean. Responses that did not match the experimentally intended target name (e.g., *bread loaf* instead of *bread*) were not considered errors but were not entered into our analyses of RT data. Figure 1 shows the RTs (top panel) and error rates (bottom panel) broken down by frequency category, and participant type, and language. Briefly summarized, the results confirmed the predictions outlined above; bilinguals showed larger frequency effects than monolinguals, and the nondominant language (Spanish) showed larger frequency effects than the dominant language (English). To assess the statistical significance of these findings we carried out separate 2 × 2 ANOVAs with frequency category (high, low) and either participant type (bilingual, monolingual) or language (English, Spanish) as independent variables, and RTs or error rates as dependent variables. The results shown in Figure 1 are subject means taken from subject analyses (*F1*) and below we also report items analyses (*F2*) and the *minF′* statistic although we do not interpret these values because of the generally accepted view that *minF′* is overly conservative (e.g., Forster & Dickinson, 1976). In addition, we report regression analyses with frequency as a continuous predictor of the size of the bilingual effect (the difference in picture naming times between bilinguals and monolinguals), and the size of the language dominance effect (the difference in naming times between English and Spanish).

The Bilingual Effect—In the analysis comparing bilinguals to monolinguals, there was a robust frequency effect such that naming times were faster for production of high than of low-frequency names $F1\ (1, 112) = 108.92$, $MSE = 7{,}010$, $\eta_p^2 = .49$, $p < .01$; $F2\ (1, 130) = 14.98$, $MSE = 95{,}752$, $\eta_p^2 = .10$, $p < .01$; $minF'\ (1, 165) = 21.37$, $p < .01$, and bilinguals showed slower naming times than monolinguals $F1\ (1, 112) = 13.78$, $MSE = 56{,}607$, $\eta_p^2 = .11$, $p < .01$; $F2\ (1, 130) = 127.63$, $MSE = 8{,}467$, $\eta_p^2 = .50$, $p < .01$; $minF'\ (1, 136) = 12.44$, $p < .01$). Most importantly, there was an interaction between participant type and frequency category such that the bilingual disadvantage was bigger for low than for high frequency words (see Figure 1); $F1\ (1, 112) = 10.27$, $MSE = 7{,}010$, $\eta_p^2 = .08$, $p < .01$; $F2\ (1, 130) = 17.25$, $MSE = 8{,}467$, $\eta_p^2 = .12$, $p < .01$; $minF'\ (1, 218) = 6.44$, $p = .01$.

The increased magnitude of frequency effects in bilinguals relative to monolinguals could not be attributed to testing order effects, or to the fact that bilinguals ultimately named fewer pictures in English-only than monolinguals. To consider these possibilities we compared the 18 bilinguals (9 run on fixed, and 9 on random order presentation) who named pictures in English-only first to a subset of the monolinguals' naming data that was matched to the 18 bilinguals for list number and presentation order (considering only the first 44 pictures named; note that these subgroups of bilinguals and monolinguals were age- and education-matched both *F*s < 1). This analysis yielded the same pattern of results as the entire group; on average the 18 bilinguals who named pictures in English-only on the first naming block, named pictures with high-frequency names 31 ms more slowly than matched monolinguals, and pictures with low-frequency names 140 ms more slowly than monolinguals (compare with 82 ms, and 153 ms respectively as shown in Figure 1). It might be suggested that 31 ms is numerically substantially smaller than 82 ms, and therefore that interference between languages may have slowed naming times for pictures with high-frequency names in English when bilinguals named pictures in Spanish-only first. However, a between-subjects ANOVA comparing bilinguals who named pictures in English-only on the first naming block (881 ms) to bilinguals who named pictures in English-only after the Spanish-only block (933 ms) showed that this difference did not even approach significance ($F1 < 1$; the same analysis with low-frequency picture naming times also revealed no slowing related to naming pictures in Spanish first $F1 < 1$).

The only difference in results that emerged when considering the bilingual disadvantage including only bilinguals who named pictures in English-only-first was that the main effect of participant type (i.e., bilinguals' slower naming times) was just marginally significant (compare with above robust main effect of participant type for the whole group) $F1$ (1, 34) = 2.54, MSE = 51,354, $\eta_p^2 = .07$, $p = .12$. However, the main effect of frequency (with faster naming times for high-frequency words) was significant $F1$ (1, 34) = 77.06, MSE = 3,946, $\eta_p^2 = .69$, $p < .01$, and most importantly, the interaction between frequency and participant type (such that the bilingual disadvantage was greater for producing low-frequency pictures names) was significant even though this analysis included less than a third of the subjects tested $F1$ (1, 34) = 13.76, MSE = 3,946, $\eta_p^2 = .29$, $p < .01$. These analyses demonstrate that that increased magnitude of the frequency effect in bilinguals versus monolinguals could not be attributed to the fact that some of the bilinguals named pictures in a Spanish-only block before naming in the English-only block, and also not to the fact that by the end of the experiment monolinguals had more practice with the naming task (monolinguals named all 132 pictures, but bilinguals named just 44 pictures, in English-only).

The increased magnitude of frequency effects in bilinguals relative to monolinguals also could not be attributed to the fact that bilinguals produced longer picture naming times than monolinguals (i.e., to a scaling effect). To evaluate this possibility we calculated a proportional frequency effects analysis in which we calculated for each subject the size of the frequency effect (mean low-frequency RT minus mean high-frequency RT) as a function of her or his own baseline (frequency effect divided by the mean overall RT). We then compared bilinguals to monolinguals in a one-way ANOVA with the proportional frequency values as the dependent variable (see Faust et al., 1999 for the assumptions inherent in proportional transformations). In this analysis, the frequency effect in bilinguals was 14.4% of their mean RT (SD = 13.2) whereas monolinguals showed a frequency effect that was 9.0% of their mean RT (SD = 5.7); this difference was statistically robust $F1$ (1, 112) = 8.11, MSE = .01, $\eta_p^2 = .07$, $p < .01$.

Because we did not match high- and low-frequency picture names for name agreement, we also considered if the results obtained could be attributed to possible differences between groups in the number of alternative names for each picture. For this analysis we repeated the 2 × 2 ANOVA including only the high- (n=39) and low-frequency (n=38) picture names that all participants (bilingual and monolingual) named using one and the same name (excluding items like *bread* which some participants called *loaf*, *loaf of bread*, or *bread loaf*). This analysis produced the same pattern of results as the main analysis (main effects of frequency, participant type, and an interaction between them; all ps < .01) suggesting that between group differences in name agreement could not explain the observed pattern of findings.

Although it is illustrative, the division of names into frequency categories is arbitrary. To address this concern, and also the fact that our low-frequency picture names were slightly longer on average than the high-frequency pictures names (see Table 2), we carried out a regression analysis in which we entered word frequency and word length (in number of phonemes) simultaneously as predictors of the bilingual effect. We also tested for an interaction between frequency and length by multiplying these predictors to create an interaction term. To reduce the multicollinearity between main effect and cross-product terms for this analysis we centered main effect vectors (by subtracting the mean from each item's score) prior to creating an interaction predictor (Aiken and West, 1991). The dependent variable in this analysis was a difference score for each picture name taking the mean naming time for monolinguals and subtracting it from the mean naming time for bilinguals; thus, larger numbers indicate more bilingual-related slowing. The regression analysis confirmed the above reported results in that the size of the bilingual disadvantage increased as word frequency decreased $\beta = -.28$, *semi-partial* $r = -.24$, $p < .01$. This analysis also revealed a trend towards a greater bilingual disadvantage with increasing word length (in number of phonemes) $\beta = .15$, *semi-partial* $r = .14$; $p = .10$. Interestingly, after multiplying the predictors (frequency and length) there was a significant interaction effect such that the bilingual disadvantage was greatest as frequency decreased and length increased $\beta = -.20$, *semi-partial* $r = -.17$, $p = .04$.

The error analyses produced a trend towards fewer naming errors for high- than for low-frequency names $F1$ (1, 112) = 21.88, $MSE = .001$, $\eta_p^2 = .16$, $p < .01$; $F2$ (1, 130) = 1.91, $MSE = .014$, $\eta_p^2 = .01$, $p = .17$; $minF'$ (1, 152) = 1.76, $p = .19$, but otherwise there were no significant effects (i.e., bilinguals did not make more errors than monolinguals, and there was no interaction between participant type and frequency; all *F*s < 1).

Language Dominance Effects—In the analysis comparing the dominant language (English) to the non-dominant language (Spanish), there was a robust frequency effect $F1$ (1, 56) = 138.02, $MSE = 32{,}464$, $\eta_p^2 = .71$, $p < .01$; $F2$ (1, 127) = 32.55, $MSE = 181{,}452$, $\eta_p^2 = .20$, $p < .01$; $minF'$ (1, 172) = 26.33, $p < .01$, and bilinguals were slower to name pictures in the nondominant language than in the dominant language $F1$ (1, 56) = 112.34, $MSE = 72{,}172$, $\eta_p^2 = .67$, $p < .01$; $F2$ (1, 127) = 150.86, $MSE = 73{,}942$, $\eta_p^2 = .54$, $p < .01$; $minF'$ (1, 137) = 64.41, $p < .01$. (Note, that the degrees of freedom for $F2$ analyses were 127 because of missing cells for one high- and two low-frequency items; there were no correct Spanish RTs for *bowl*, *badge*, and *plunger*). Most importantly, there was an interaction between language dominance and frequency category (see Figure 2) such that bilinguals showed bigger frequency effects in the nondominant language than in the dominant language $F1$ (1, 56) = 19.46, $MSE = 48{,}817$, $\eta_p^2 = .23$, $p < .01$; $F2$ (1, 127) = 15.90, $MSE = 73{,}942$, $\eta_p^2 = .11$, $p < .01$; $minF'$ (1, 167) = 8.75, $p < .01$.

The increased magnitude of frequency effects in the nondominant Spanish relative to dominant English could not be attributed to testing order effects. To consider this possibility we repeated our 2 × 2 ANOVA this time with language (English or Spanish) as a between-subjects factor comparing the 18 bilinguals (9 run on fixed, and 9 on random order presentation) who named pictures in English-only first to the 18 bilinguals who named pictures in Spanish-only first. This analysis yielded the same pattern of results and statistical significance (all *p*s < .01) as the analysis of all bilinguals; on average bilinguals who named pictures in English-only in the first naming block, showed a frequency effect of 181 ms in English and bilinguals who named pictures in Spanish-only in the first naming block showed a frequency effect of 581 ms in Spanish (compare with 151 ms, and 409 ms respectively as shown in Figure 1). The only evidence of an effect of testing order we obtained was when we included testing order in our analysis of language dominance effects (for the purpose of brevity we do not report the full details of this analysis). In this analysis, (although there was no main effect of testing order; $p = .17$) we obtained a three-way interaction between frequency, language dominance, and testing order such that bilinguals tested in English-only first showed similarly sized frequency effects in English and Spanish, whereas all other bilinguals showed a greater frequency effect in Spanish than in English; $F1$ (2, 54) = 8.82, $MSE = 38{,}162$, $\eta_p^2 = .25$, $p < .01$.

The increased magnitude of frequency effects in the less-dominant relative to the dominant language also could not be attributed to the fact that bilinguals produced longer picture naming times in their less-dominant language. To evaluate this possibility we calculated a proportional frequency effect analysis (see above) comparing the magnitude of the frequency effect in Spanish and English (a repeated factor within subjects) in a one-way ANOVA. In this analysis, the frequency effect in Spanish was 29.4% of the mean Spanish RT ($SD = 22.9$) whereas English showed a frequency effect that was only 14.4% of the mean English RT ($SD = 13.2$); this difference was statistically robust $F1$ (1, 56) = 15.64, $MSE = .04$, $\eta_p^2 = .22$, $p < .01$.

Because we did not match high- and low-frequency picture names for name agreement, we also considered if the results obtained could be attributed to possible differences between languages in the number of alternative names for each picture. For this analysis we repeated the 2 × 2 ANOVA including only the high- (n=42) and low-frequency (n=30) picture names that had 100% name agreement (based on bilinguals in the current study) in English and in Spanish. This analysis produced the same pattern of results as the main analysis (main effects of frequency, participant type, and an interaction between them; all ps < .01) suggesting that differences between English and Spanish in name agreement could not explain the observed findings.

To determine if similar results are obtained when treating word frequency as a continuous variable we carried out a regression analysis in which we entered word frequency as a predictor of language dominance effects. In addition to frequency, in this analysis we simultaneously entered the difference in word length in phonemes between languages as a predictor (Spanish name length minus English name length) to control for the fact that Spanish words tend to be longer than English words (see Table 3). The dependent variable in this analysis was a difference score for each picture name taking the mean naming time for the English name and subtracting it from the mean naming time for its Spanish translation equivalent. The regression analysis confirmed the above reported results in that the degree to which English was dominant over Spanish was systematically smaller as word frequency increased $\beta = -.299$, *semi-partial* $r = -.298$, $p < .01$. However, the degree to which English was more accessible relative to Spanish was not predicted by between-language differences in word length $t < 1$. In other words, bilinguals were English-dominant particularly for producing lower-frequency names because of their lower frequency of use, but not because Spanish words were longer than English words[2].

The error analyses also produced significant frequency effects with more naming errors for low-frequency picture names $F1$ (1, 56) = 43.73, $MSE = .004$, $\eta_p^2 = .44$, $p < .01$; $F2$ (1, 130) = 9.72, $MSE = .021$, $\eta_p^2 = .07$, $p < .01$; $minF'$ (1, 174) = 7.95, $p = .01$, significant language dominance effects with more errors in the nondominant Spanish than in the dominant English $F1$ (1, 56) = 27.51, $MSE = .007$, $\eta_p^2 = .33$, $p < .01$; $F2$ (1, 130) = 49.39, $MSE = .004$, $\eta_p^2 = .28$, $p < .01$; $minF'$ (1, 120) = 17.66, $p < .01$, and as just described (in the RT data) there was also an interaction between frequency and language dominance such that bilinguals made more picture naming errors in the less dominant language but this was especially true for pictures with low-frequency names (see Figure 2); $F1$ (1, 56) = 14.34, $MSE = .005$, $\eta_p^2 = .20$, $p < .01$; $F2$ (1, 130) = 17.89, $MSE = .004$, $\eta_p^2 = .12$, $p < .01$; $minF'$ (1, 142) = 7.96, $p = .01$.

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[2] An exploratory regression analysis in which we entered frequency and length of the Spanish names (in number of phonemes), and the interaction term as predictors (with main effect predictors centered prior to creating the interaction term; Aiken & West, 1991) showed a significant effect of frequency $\beta = -.38$, *semi-partial* $r = -.26$, $p < .01$ as a predictor of language dominance. In addition, length of Spanish names was just significant $\beta = -.18$, *semi-partial* $r = .16$, $p = .05$, and the interaction between length and frequency was a marginally significant predictor $\beta = -.19$, *semi-partial* $r = -.13$, $p = .11$. Thus, length of the name in the nondominant language may be critical for predicting the size of language dominance effects. However, because this analysis was not planned a priori, and produced just significant and marginally significant results, we refrain from interpreting it any further.

Discussion

The results of Experiment 1 provide direct support for the weaker links hypothesis by replicating the finding that bilinguals name pictures more slowly than monolinguals (Gollan, Montoya, et al., 2005), and by showing that the difference between groups is more pronounced for low-frequency words. That is, bilinguals show bigger frequency effects in picture naming because reduced language use affects low-frequency names more than high-frequency names (in the General Discussion we consider the alternative possibility that between group differences in lexicon size is critical, and also consider how the interference hypothesis could account for the observed pattern of results). Additional support for the weaker links hypothesis comes from the finding that within the bilingual group the difference between naming times in the dominant and nondominant languages was more pronounced for production of low-frequency words. That is, frequency effects in picture naming are larger in the nondominant than in the dominant language (similar findings were reported for written word recognition in Dutch-English bilinguals; Duyck, Vanderelst, Desmet, & Hartsuiker, 2005). The change in the size of the frequency effect was obtained in terms of categorical manipulations of frequency on unadjusted naming times, with continuous analyses, with each group providing its own baseline in a percent-frequency-effect analysis, in analyses restricted to items with 100% name agreement, and in between subjects analyses comparing only bilinguals who named pictures in English-only first to monolinguals, and comparing bilinguals who named pictures in English-only first to bilinguals who named pictures in Spanish-only first. Assuming that bilinguals use their dominant language less often than monolinguals, and that bilinguals use the nondominant language less often than the dominant one (see Table 2), these results clearly associate decreased amount of language use over time with an increase in the size of the frequency effect in picture naming times.

These conclusions depend on the assumption that frequency per se – not one of several variables that are highly correlated with word frequency (e.g., Gilhooly & Logie, 1980) – produced the pattern of results we obtained. We did not attempt to control for every possible confound because this would severely limit the materials included in the study. However, additional analyses supported the idea that frequency exerts independent effects on naming times. In these analyses, we included frequency and either length in English (for the bilingual effect) or length differences between English and Spanish (for language dominance effects) as continuous variables. These analyses indicated that word frequency, word length, and the interaction between them explained unique variance in the magnitude of the bilingual effect, but only frequency (not length differences between Spanish and English names) influenced the magnitude of language dominance effects. The interaction between frequency and length for predicting the bilingual disadvantage has implications for the locus of the bilingual effect (which we discuss in the General Discussion). Given the significant effects of word length on the size of the bilingual disadvantage, it is not clear why we failed to obtain length effects on language dominance (but see footnote 2). However, this difference suggests that partially distinct mechanisms are involved in explaining bilingual effects and language dominance effects.

It is beyond the scope of the present study to determine how language dominance effects differ from bilingual effects, however, in attempting to understand the interaction between language dominance and frequency effects in future studies it may be useful to consider the effects of testing order. We observed a significant three-way interaction between testing order, frequency category, and language such that bilinguals who named pictures in the English-only condition first showed a similarly sized frequency effect in the dominant (i.e., English) and nondominant (i.e., Spanish) languages (whereas bilinguals who named pictures in Spanish-first or in the either-language condition first showed a much larger frequency effect in Spanish than in English). It is difficult to understand why naming pictures in English-only first would reduce the size of the frequency effect in Spanish. A priori it would have seemed more likely that naming pictures in Spanish first might influence subsequent naming in English (because Spanish would normally be relatively inactive for English-dominant bilinguals prior to naming pictures in a Spanish-only block). In this case, however, it seemed that naming pictures in a relatively easy block (English) first, speeded naming times for low-frequency words in a subsequent more difficult (Spanish) testing block, thereby reducing the overall difference between easy (English) and difficult (Spanish) items. This pattern of results is also difficult to understand given prior observations of bigger differences between easy and difficult items (in this case concrete versus abstract words in lexical decision), when the easy (concrete) block precedes the more difficult (abstract) block (Kroll & Merves, 1986). Most importantly, however, the interaction between language and frequency (such that the frequency effect was larger in the nondominant than in the dominant language) was robust in a between subjects analysis comparing English RTs of bilinguals tested in English-only first to Spanish RTs of bilinguals tested in Spanish-only first. This analysis indicates that – completely independently of testing order effects – the size of the frequency effect was larger in the nondominant than in the dominant language (i.e., the interaction between language dominance and frequency was not caused exclusively by testing order effects), and this provides support for the weaker links hypothesis.

It might be suggested that the bilingual disadvantage and language dominance effects were obtained because of differences in AoA (i.e., bilinguals learned English at a later age than monolinguals, and at a later age than they learned Spanish). To determine whether AoA differences across the bilingual/monolingual and dominant/nondominant language contrasts could explain the pattern of results we conducted a separate ratings study. Twenty bilinguals and twenty-one monolinguals recruited from the same population as in Experiment 1 rated the picture names on a scale with nine possible ratings (age 2, 3, 4, 5, 6 to 7, 8 to 9, 10 to 12, over 13, “don’t know the word”). To determine an average AoA rating for each picture name, ratings with a range (e.g., 6 to 7) were given the value in the middle of the range (e.g., 6.5), and both the “over 13” and the “don’t know the word” ratings were entered as 13. Bilinguals completed the ratings in English first and then in Spanish, and monolinguals rated only the English words. Objective and subjective AoA measures are highly correlated (see review by Juhasz, 2005); we used subjective ratings because it is not clear to what extent monolingual norms would apply to bilinguals. The ratings results are shown in Table 4.

To determine whether between group differences in AoA could explain the observed pattern of bilingual disadvantages and language dominance effects we considered whether low-frequency names showed a bigger AoA discrepancy between bilinguals and monolinguals than high-frequency names, and within bilinguals whether low-frequency names showed a bigger AoA discrepancy between Spanish and English than high frequency names (Izura & Ellis, 2002; 2004 demonstrated that AoA effects reflect the age at which words are learned in each specific language). Although AoA differences were in the right direction (see Table 4) for explaining the bilingual disadvantage, the differences were quite small. Bilinguals reported learning both high-frequency and low-frequency English words about a year and a half later than monolinguals. Specifically, 1.5 and 1.7 years later, respectively, thus displaying only a very small tendency (a difference of only 0.2 years) in the right direction for explaining the bilingual effect. In addition AoA differences were in the wrong direction for explaining the pattern of language dominance effects observed in Experiment 1; bilinguals reported learning low-frequency names in both Spanish and English at about the same age, but they reported learning high-frequency words in Spanish almost a year before (on average) learning their English translations. Thus, if AoA were solely responsible for the observed effects, we should have observed similar RTs in Spanish and English for low-frequency names and faster response times in Spanish than in English for high-frequency names (greater language dominance effects on high-frequency words). Instead, we obtained slower naming times in Spanish, and significantly larger language dominance effects on low-frequency words (see Figure 1).

In light of these findings, it might be possible to claim that the bilingual disadvantage should be attributed solely to AoA, whereas language dominance effects should be attributed to frequency differences; however, a more probable explanation is that both frequency and AoA contributed to the differences we observed, and in the case of language dominance effects frequency was a more powerful predictor of picture naming times than AoA. Thus, in addition to providing direct support for the weaker links hypothesis, the results of Experiment 1 provide corroborating evidence for the emerging consensus that frequency influences lexical accessibility independently of a host of variables that tend to correlate with frequency.

As a further test of the relationship between frequency of use and lexical accessibility, in Experiment 2 we examined how the effects of bilingualism and language dominance change with increased age.

Experiment 2

As outlined in the introduction, the weaker links hypothesis together with activation based accounts of the frequency effect in language production predict that (a) frequency effects, (b) the bilingual disadvantage and (c) language dominance effects should become smaller with increased age. In contrast, the interference account predicts that the bilingual disadvantage should increase in older age if older bilinguals are less able to control between language interference than younger bilinguals (Hernandez & Kohnert, 1999), and if the frequency effect arises at the same locus as competition between languages. The first prediction, that frequency effects should be smaller in older adults, has been examined in monolingual studies of word recognition but with no consensus result across studies. Consistent with the notion of a ceiling on the degree to which increased use affects lexical accessibility, one study found significant frequency effects in younger but not in older adults for reading words aloud (Morrison, Hirsh, Chappell, & Ellis, 2002; in this study frequency was manipulated only within the constraints of a strict control for AoA). However, other studies have found similarly sized frequency effects in younger and older adults in the lexical decision task (e.g., Allen, Madden, Weber, & Groth, 1993; Bowles & Poon, 1981; Tainturier, et al., 1989), or even larger frequency effects in older than in young adults (e.g., Balota & Ferraro, 1993, 1996; Spieler & Balota, 2000).

Relatively few studies have examined how frequency effects may or may not change with increased age in picture naming, and these also do not provide a consistent answer in terms of how frequency and age interact to affect naming times. One unpublished study found larger frequency effects in older than in younger adults in picture naming times but no adjustment for age-related slowing was reported (Chae, Burke, Ketron, 2002). Another study found similarly sized frequency effects on picture naming accuracy (they did not measure RTs) in adults aged 20–70 (Newman & German, 2005)[3]. In the current context, the tendency for some studies to show greater frequency effects in older than in younger adults (whether in production in Chae, et al., 2002 or in comprehension in Balota & Ferraro, 1993, 1996; Spieler & Balota, 2000) is particularly problematic for the weaker links and activation accounts because

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[3] Studies examining AoA effects on picture naming RTs (with early versus late AoA items matched for frequency) also do not provide a clear answer in terms of how AoA and age may interact to affect picture naming times. In one study, AoA effects were virtually identical in size in young (78 ms) and older (70 ms) adults even though older adults had much longer picture naming times (454 ms and 443 ms longer for early versus late acquired items respectively; Barry, Johnston & Wood, 2006). In another study there was a trend towards smaller AoA effects in older adults (Morrison, et al, 2002), again even though older adults named pictures more slowly than young adults (306 ms and 261 ms more slowly for early versus late acquired items respectively). Finally, another study found what appeared to be stronger AoA effects with increased age; AOA influenced naming accuracy (RTs were not examined) in older but not in young adults (Newman & German, 2005; early versus late items in this study were matched for frequency, familiarity, neighborhood density, and length were controlled).

increased use should lead to smaller frequency effects. Increased frequency effects in older relative to younger adults also creates problems for all models in which frequency effects are analogous to learning effects (e.g., Plaut, et al., 1996) because frequency effects should decrease with increased use in such models (see discussion in Murray & Forster, 2004; Spieler & Balota, 2000).

However, increased age likely affects lexical accessibility in more than one way (Gollan & Brown, 2006; Newan & German, 2005; see Spieler & Balota, 2000 for an interesting approach to this problem) and it is possible that the effects of increased use are only observable (in the form of a smaller frequency effect) if other age effects (e.g., age related decline in lexical accessibility; Burke, MacKay, Worthley, & Wade, 1991) do not counteract the effects of increased use[4]. Using an activation based account we predicted that the effects of increased use associated with increased age should be more robust for production in the nondominant language. In other words, as people age, frequency effects should decrease, but the age related attenuation of the frequency effect should be especially apparent for nondominant language production. This prediction is based on the assumption that the nondominant language is used less often than the dominant language (over the course of a life-time) and that lexical representations in the nondominant language would therefore be further from ceiling levels of activation than representations in the dominant language.

Method

Participants

Twenty-one cognitively healthy monolinguals and twenty cognitively healthy Spanish-English bilinguals were recruited for participation from the University of California, San Diego (UCSD) Alzheimer's Disease Research Center (ADRC; see Gollan, et al., 2007 for further details about the elderly bilingual population at the ADRC). Participants were diagnosed as cognitively intact by two senior staff neurologists using criteria developed by the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) and the Alzheimer's Disease and Related Disorders Association (ADRDA; McKhann, et al., 1984) and based on medical, neurological, and neuropsychological evaluations and a number of laboratory tests (to rule out dementia). Three additional Spanish-English bilinguals (who were spouses of ADRC participants) also participated in the study and were assumed to be cognitively intact based on high levels of reported functioning in their daily lives, and their Dementia Rating Scale (DRS; Mattis, 1988), and Mini Mental State Examination (MMSE; Folstein, Folstein & McHugh, 1975) scores.

Older and younger bilinguals (taken from Experiment 1) were matched on a subject-by-subject basis for ability to translate in both directions (i.e., from Spanish to English and from English to Spanish). There were 14 pairs of younger and older bilinguals with nearly perfectly matched translation scores. In addition, we selected 14 pairs of older and younger monolinguals (taken from Experiment 1) while matching monolinguals and bilinguals in both age-groups as closely as possible for education level. To determine education level we used the degree level completed (e.g., 12 years for high school, 16 for a BA, 18 for Master's degree etc), or if a degree was not completed we used the number of years completed.

Table 5 shows the translation scores, the cognitive assessment scores for older participants, and for all participants the self reported measures of language history. Table 6 shows statistics for the comparisons of interest in Table 5; that is, two-tailed t-tests for comparisons of bilinguals

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[4] Other data also associate increased use with a smaller frequency effects. For example, people with higher levels of education (which arguably leads to increased language use) show smaller sized frequency effects than people with lower levels of education (e.g., Caza & Moscovitch, 2005; Tainturier, Tremblay, & Lecours, 1992; see also Newman & German, 2005).

and monolinguals within each age group, and younger to older participants within language groups. Across all comparisons participants did not differ in education level (all *p*s > .26). Relative to monolinguals, the bilinguals in both age groups translated more names correctly into another language, reported using English less often, learned English at a later age and another language at an earlier age, and rated themselves as more proficient in speaking another language (all *p*s ≤ .01). The older bilinguals also rated their ability to speak English as lower than the older monolinguals (younger bilinguals did not show this pattern in Experiment 2 but see Experiment 1). Within the older participants, bilinguals and monolinguals did not differ on mental status (MMSE scores), but bilinguals had lower DRS scores. The lower DRS scores in bilinguals likely reflect the inclusion of two semantic category fluency trials (which show a robust bilingual disadvantage) in this test (Gollan et al., 2002;Rosselli et al., 2000).

Within the bilinguals, younger and older bilinguals did not differ on ability to translate into English and into Spanish, on reported use of English, or age of exposure to English (all *p*s > .21). It might be suggested that younger and older bilinguals should be matched for proficiency using the bilinguals' proficiency ratings (instead of the objective translation scores we used). A potential problem with this approach is that younger and older adults might have different standards of performance for self-ratings of proficiency, or older adults might rate themselves as less proficient because of their sense of increasing word-finding problems with increased age (e.g., Burke, et al., 1991). Consistent with this hypothesis, despite their carefully matched ability to produce correct untimed translations, younger bilinguals rated their ability to speak English as significantly higher than older bilinguals, and there was a marginally significant trend in the same direction for Spanish ratings. Similarly, younger monolinguals also tended to rate their ability to speak English and another language as better than did older monolinguals. These findings support the idea that older adults (whether bilingual or monolingual) perceive themselves as "less proficient" language users (in both languages for bilinguals) in some cases despite subsequently demonstrating equivalent performance to younger adults on some objective measures of verbal knowledge (e.g., translation scores). Younger monolinguals also rated themselves as more proficient in a non-English language than older monolinguals, however, in this case the ratings were corroborated by objective findings. That is, younger monolinguals were also marginally significantly better able to translate into another language, and were exposed to another language at a marginally significantly younger age than older monolinguals. Finally, younger and older adults seemed to interpret the age-of-acquisition question somewhat differently with most of the older adults reporting "zero" whereas younger adults sometimes reported the age at which they began speaking themselves.

Materials and Procedure

These were identical to those in Experiment 1 with the exception that older participants were tested in their homes using a Macintosh G3 PowerBook with a 14 inch screen. Picture files were adjusted so that the size that appeared on the laptop matched those shown in Experiment 1. Three of the older bilinguals, two of the older monolinguals, and six of the younger bilinguals included in the matching procedure were tested on the random presentation version of the experiment. The remaining participants were tested on the fixed order version.

Results

Figure 2 shows the RTs (top panel) and error rates (bottom panel) broken down by frequency category, and bilingual status, age group, and language dominance. Briefly summarized, we replicated the results of Experiment 1 in that bilinguals showed bigger frequency effects than monolinguals, and the nondominant language showed bigger frequency effects than the dominant language. In addition, frequency effects showed nonsignificant trends (only in *F1* analyses) towards larger frequency effects with increased age in both monolinguals' and bilinguals' naming times in English, but frequency effects were smaller with increased age for bilinguals' naming times in Spanish. To assess the statistical significance of these findings we carried out separate 2 × 2 × 2 ANOVAs with age (younger, older), frequency category (high, low) and either participant type (bilingual, monolingual) or language (dominant, nondominant) as independent variables and RTs and error rates as dependent variables. The results shown in Figure 2 are subject means taken from subject analyses (*F1*) and below we also report items analyses (*F2*) and the *minF′* statistic.

The Bilingual Effect—In the analysis comparing bilinguals to monolinguals across age groups on English naming times, there was a robust frequency effect such that speakers named pictures with high-frequency names more quickly than pictures with low-frequency names *F1* (1, 52) = 62.50, *MSE* = 10,602, $\eta_p^2 = .55$, $p < .01$; *F2* (1, 126) = 13.18, *MSE* = 259,948, $\eta_p^2 = .09$, $p < .01$; *minF′* (1, 167) = 10.88, $p < .01$, a robust effect of participant type such that bilinguals showed slower naming times than monolinguals *F1* (1, 52) = 8.13, *MSE* = 136,081, $\eta_p^2 = .14$, $p = .01$; *F2* (1, 126) = 65.30, *MSE* = 91,212, $\eta_p^2 = .34$, $p < .01$; *minF′* (1, 165) = 7.23, $p = .01$, and a significant age effect such that older participants had slower naming times than younger participants *F1* (1, 52) = 18.54, *MSE* = 136,081, $\eta_p^2 = .26$, $p < .01$; *F2* (1, 126) = 88.93, *MSE* = 133,481, $\eta_p^2 = .41$, $p < .01$; *minF′* (1, 75) = 15.34, $p < .01$. As in Experiment 1, the bilingual disadvantage (effect of participant type) was bigger for low- than for high-frequency words; this interaction was marginally significant both by subjects *F1* (1, 52) = 3.91, *MSE* = 10,601, $\eta_p^2 = .07$, $p = .05$ and items analyses *F2* (1, 126) = 3.74, *MSE* = 91,212, $\eta_p^2 = .03$, $p = .06$; *minF′* (1, 150) = 1.91, $p = .17$.

Interestingly, the size of the bilingual disadvantage and of frequency effects was constant across age groups; there was no hint of an interaction between bilingual status and age group (both *F*s < 1), and although there was a marginally significant trend towards larger frequency effects in older than in younger adults by subjects *F1* (1, 52) = 3.22, *MSE* = 10,601, $\eta_p^2 = .06$, $p = .08$ this trend did not approach significance in the items analysis (*F2* < 1; *minF′* < 1). The trend also was not significant in an analysis of proportional frequency effects (*F1* < 1) in which the frequency effect in older adults (collapsed across the bilingual/monolingual contrast) was about 15% of their mean RT (*M* = 14.9, *SD* = 12.8) whereas younger adults showed a frequency effect that was about 12% of their mean RT (*M* = 12.2, *SD* = 10.1). Finally, there was no hint of a three-way interaction between bilingual status (participant type), age group, and frequency category (all *F*s < 1; Note the degrees of freedom for these item analyses were 126 instead of 130 because of missing data points in one or three cells for the items *keyboard*, *vacuum*, *blowdryer*, and *steering wheel*).

In the error analyses, the frequency effect (with fewer errors for producing high-frequency pictures names) was significant by subjects *F1* (1, 52) = 9.97, *MSE* = .001, $\eta_p^2 = .16$, $p < .01$ but not by items *F2* (1, 130) = 2.06, *MSE* = .03, $\eta_p^2 = .02$, $p < .15$; *minF′* (1, 171) = 1.71, $p = .19$, and bilinguals did not make significantly more errors than monolinguals *F1* < 1; *F2* (1, 130) = 1.32, *MSE* = .007, $\eta_p^2 = .01$, $p = .25$; *minF′* < 1. However, older adults made more errors than younger adults *F1* (1, 52) = 12.27, *MSE* = .003, $\eta_p^2 = .19$, $p < .01$; *F2* (1, 130) = 12.20, *MSE* = .01, $\eta_p^2 = .08$, $p < .01$; *minF′* (1, 149) = 6.12, $p = .01$. All other 2-way and 3-way interactions did not approach significance (all *F*s < 1) with one unexpected exception which was a significant 2-way interaction between bilingual status and age *F1* (1, 52) = 5.29, *MSE* = .003, $\eta_p^2 = .09$, $p = .03$; *F2* (1, 130) = 8.49, *MSE* = .008, $\eta_p^2 = .06$, $p < .01$; *minF′* (1, 119) = 3.26, $p = .07$. Younger bilinguals made slightly fewer errors (2.8%) than monolinguals (4.3%), whereas older bilinguals made slightly more errors (8.8%) than older monolinguals (5.6%). This interaction is difficult to explain and we do not interpret the results of the errors analyses any further. In previous studies bilinguals either made the same number of errors as (Gollan, Montoya, et al., 2005, Experiment 1; see also Experiment 1 above), or bilinguals made more errors than, monolinguals (e.g., Gollan, Montoya, et al., 2005, Experiment 2).

Language Dominance Effects

In the analysis comparing RTs in the dominant language (English) to RTs in the nondominant language (Spanish), bilinguals named pictures with high-frequency names faster than pictures with low-frequency names *F1* (1, 26) = 9.21, *MSE* = 156,621, $\eta_p^2 = .26$, $p = .01$; *F2* (1, 105) = 19.29, *MSE* = 410,231, $\eta_p^2 = .16$, $p < .01$; *minF′* (1, 54) = 6.23, $p = .02$, and bilinguals named pictures more slowly in Spanish than in English *F1* (1, 26) = 59.11, *MSE* = 33,592, $\eta_p^2 = .70$, $p < .01$; *F2* (1, 105) = 21.15, *MSE* = 201,922, $\eta_p^2 = .17$, $p < .01$; *minF′* (1, 128) = 15.57, $p < .01$. In addition, older bilinguals named pictures marginally more slowly than younger bilinguals by the subjects analysis *F1* (1, 26) = 3.56, *MSE* = 259,401, $\eta_p^2 = .12$, $p = .07$ and significantly more slowly according to the items analysis *F2* (1, 105) = 16.05, *MSE* = 238,075, $\eta_p^2 = .13$, $p < .01$; *minF′* (1, 38) = 2.91, $p = .10$.

There were a number of significant two-way interactions but all of these were qualified by a significant 3-way interaction that is reported below. Note the degrees of freedom for item analyses in this and the next paragraph are 105 because of missing data points for naming times in the nondominant language. As in Experiment 1, the effect of language dominance was larger for low than for high frequency words *F1* (1, 26) = 4.11, *MSE* = 37,304, $\eta_p^2 = .14$, $p = .05$; *F2* (1, 105) = 6.54, *MSE* = 238,296, $\eta_p^2 = .06$, $p = .01$; *minF′* (1, 63) = 2.52, $p = .12$, however only younger (but not older adults) showed this pattern (see three-way interaction below and Figure 2). There was a trend towards a two-way interaction between age and frequency *F1* (1, 26) = 3.43, *MSE* = 1,985,533, $\eta_p^2 = .11$, $p = .08$; *F2* < 1; *minF′* < 1) with young adults showing a trend towards larger frequency effects. Similarly, there was a trend towards a two-way interaction between age group and language dominance effects *F1* (1, 26) = 2.09, *MSE* = 33,592, $\eta_p^2 = .07$, $p = .16$; (*F2* < 1; *minF′* < 1 with young adults tending to show bigger language dominance effects).

Most interestingly, whereas younger bilinguals showed extremely large frequency effects in the non-dominant language (486 ms; see also Experiment 1), older bilinguals showed equivalent frequency effects in the nondominant and dominant languages (see Figure 2). This three-way interaction between age group, language dominance, and frequency category was statistically significant *F1* (1, 26) = 6.93, *MSE* = 37,304, $\eta_p^2 = .21$, $p = .01$; *F2* (1, 105) = 4.97, *MSE* = 238,296, $\eta_p^2 = .05$, $p = .03$; *minF′* (1, 101) = 2.89, $p = .09$. Post-hoc comparisons revealed a trend towards age-related slowing for naming pictures with high-frequency names in Spanish *F1* (1, 26) = 2.56, *MSE* = 9,985, $\eta_p^2 = .09$, $p = .12$, but no hint of an age related slowing for producing pictures with low-frequency names in Spanish (*F1* < 1). In addition, language dominance effects were similarly sized in older and younger adults for high-frequency names alone (there was no interaction between age group and language dominance effects *F1*<1), but language dominance effects were significantly smaller in older than in younger adults for low-frequency names alone; there was a significant interaction between age group and language dominance *F1* (1, 26) = 6.56, *MSE* = 121,255, $\eta_p^2 = .19$, $p = .02$.

Importantly, the three way interaction between age, language dominance, and frequency could not be attributed to testing order effects. Recall that in Experiment 1 we found that the young bilinguals tested in an English-only block first showed similarly sized frequency effects in the dominant (English) and nondominant (Spanish) languages. As such, if most or all of the older bilinguals had all been tested in English-only first, but some of the young bilinguals were tested in Spanish-only first, this might have produced the pattern of results shown in Figure 2. Although we counterbalanced testing order in Experiment 2 for both younger and older bilinguals, our procedure of matching bilinguals for translation scores resulted in our including 7 older bilinguals who were tested in English-only first, and only 4 younger bilinguals who were tested in English-only first. Importantly, the three way interaction between age, language dominance, and frequency effects was still significant after excluding all bilinguals who were tested in English-only first *F1*(1, 15) = 16.14, *MSE* = 27,289, $\eta_p^2 = .52$, $p < .01$. Although our ability to fully explore testing order effects in Experiment 2 is limited by the low number of participants in each testing order, these analyses (combined with the order effects reported in Experiment 1), do at least increase our confidence that the interaction between age, language dominance, and frequency should not be attributed exclusively to testing order effects.

In the analysis comparing error rates in the dominant language (English) to error rates in the nondominant language (Spanish), there was a robust frequency effect with fewer errors for producing pictures with low-frequency names *F1* (1, 26) = 16.39, *MSE* = .004, η_p^2 = .39, *p* < .01; *F2* (1, 130) = 7.03, *MSE* = .06, η_p^2 = .05, *p* = .01; *minF′* (1, 138) = 4.92, *p* = .03, bilinguals made more naming errors in Spanish than in English, *F1* (1, 26) = 31.80, *MSE* = .003, η_p^2 = .55, *p* < .01; *F2* (1, 130) = 19.35, *MSE* = .02, η_p^2 = .13, *p* < .01; *minF′* (1, 118) = 12.03, *p* < .01, and older bilinguals made more naming errors than younger bilinguals; this age effect was marginally significant in the subjects analysis, *F1* (1, 26) = 3.37, *MSE* = .02, η_p^2 = .12, *p* = .08 and significant in the items analysis, *F2* (1, 130) = 7.83, *MSE* = .03, η_p^2 = .06, *p* < .01; *minF′* (1, 51) = 2.36, *p* = .13. The effect of language dominance was significantly bigger for low than for high frequency words *F1* (1, 26) = 15.82, *MSE* = .003, η_p^2 = .38, *p* < .01; *F2* (1, 130) = 9.80, *MSE* = .02, η_p^2 = .07, *p* < .01; *minF′* (1, 117) = 6.05, *p* = .02; in this case (unlike in the RT data) both younger and older adults showed this pattern (see Figure 2). There was a trend towards bigger frequency effects in older than in younger bilinguals *F1* (1, 26) = 3.97, *MSE* = .02, η_p^2 = .13, *p* = .06; (*F2* < 1; *minF′* < 1; with younger adults showing a trend towards larger frequency effects; but see below). Similarly, there was a nonsignificant tendency for younger adults to show bigger language dominance effects (a two-way interaction between age group and language dominance *F1* < 1; *F2* (1, 130) = 3.47, *MSE* = .02, η_p^2 = .03, *p* = .07; *minF′* < 1. In this case the three-way interaction was not significant *F1* (1, 26) = 1.90, *MSE* = .003, η_p^2 = .07, *p* = .18; *F2* (1, 130) = 1.44, *MSE* = .02, η_p^2 = .01, *p* = .23; *minF′* < 1. However, the general pattern of results in the error analysis was the same as that in the RTs analyses in that younger adults made slightly more errors than older adults for naming pictures with low-frequency names in the nondominant language, but slightly fewer errors than older adults for naming pictures with high-frequency names in the nondominant language.

The results of Experiment 2 replicated the results reported in Experiment 1 in that bilinguals showed bigger frequency effects than monolinguals, and the nondominant language showed bigger frequency effects than the dominant language. In addition, whereas bilingual effects and frequency effects remained stable with increased age, language dominance effects were smaller in older than in younger adults, but only for pictures with low-frequency names. Because we had a much smaller number of participants in Experiment 2 we did not fully explore the possibility that testing block order may have differentially affected older versus younger bilinguals (e.g., some participants named pictures in Spanish-only first and then switched languages to name pictures in an English-only block). However, it is unlikely that testing order effects alone produced the pattern of results we obtained because the interaction between age, language dominance, and frequency was still significant after we excluded bilinguals who named pictures in an English-only block first (which according to our analysis of testing order effects in Experiment 1 produced an “artificially” balanced profile for frequency effects in the two languages). It might be also be suggested that older bilinguals showed a different profile of language dominance effects because they were differentially affected by having to switch languages between testing blocks than young bilinguals. However, we consider this to be unlikely because task switching costs are short-lived in both younger (e.g., Rogers & Monsell, 1995) and older adults (e.g., Salthouse, Fristoe, McGuthry, & Hambrick, 1998).

General Discussion

In the current investigation young and older monolinguals and bilinguals named pictures with high- and low frequency names for the purpose of constraining accounts of how bilingualism affects language production, and to develop accounts of the frequency effect in models of language production. Based on the proposal that bilinguals use words in each language less often than monolinguals (the weaker links account), and the ceiling effect on the degree to which increased use leads to increased lexical accessibility (the activation hypothesis), we predicted that the bilingual disadvantage should be smaller for high- than for low-frequency words, and should decrease with increased age. In contrast, based on the idea that translations compete for selection (the interference account), we predicted that the bilingual disadvantage either would not be modulated by word frequency (if frequency effects arise after lexical selection), or that the bilingual disadvantage would be greater for producing high-frequency names (which compete more fiercely between languages) than low-frequency names, and would increase with age if older bilinguals are less able to manage competition between languages than young bilinguals.

The results of Experiment 1 clearly supported the predictions of the weaker links hypothesis, and of activation based accounts of the frequency effect. Bilingualism (see also Ivanova & Costa, in press) and production of the nondominant language (see also Duyck, et al., 2005) were associated with larger frequency effects. The increased frequency effects in bilinguals relative to monolinguals, and in the nondominant than in the dominant languages, could not be attributed to testing order (i.e., some bilinguals named pictures in their nondominant language first), to AoA effects, to between (participant or language) group differences in name-agreement for target picture names, or to scaling effects. Proportional analyses in which we adjusted frequency effects to consider baseline differences in overall response time displayed a progression such that monolinguals (9%), bilinguals in the dominant language (English; 14%), and bilinguals in the non-dominant language (Spanish; 29%) showed increasingly larger frequency effects thereby clearly associating decreased use with an increased frequency effect.

These results are problematic for the interference account in which high-frequency translation equivalents will be highly active and competing for selection more strongly than low-frequency names in the nondominant language (e.g., *pulpo*) which might not be sufficiently active to compete for selection in time to affect dominant language production (i.e., *octopus*). To accommodate the results of Experiment 1, competition for selection between translation equivalents (e.g., Green, 1998; Hermans et al., 1998; Lee & Williams, 2001; Kroll et al., 2006) would have to be instantiated such that low-frequency targets would suffer more from the addition of translation equivalent competitors than high-frequency targets. It is not clear what would motivate such an adjustment (other than explaining the data) or exactly how it should be implemented. However, some data from monolingual production seem to call for a similar arrangement. For example, monolingual speakers are slower to name pictures with more than one alternative name (e.g., *TV*, *television*) but only when the two names are also relatively low-frequency (e.g., *limousine*, *limo*; Spieler & Griffin, 2006; but see Griffin, 2001). In addition, low-frequency distractors produce greater interference than high-frequency distractors in the picture-word interference paradigm (Miozzo & Caramazza, 2003). Note however, that this “counterintuitive” effect of distractor frequency does not provide grounds for predicting that high-frequency names should suffer less interference from high-frequency competitors than would low-frequency names from low-frequency competitors (which is effectively what is happening in Experiment 1 if the results are to be attributed to competition).

Another potential complication for the interference account was that there was an independent contribution of word length to the bilingual disadvantage, and an interaction between length and frequency suggesting that both frequency effects and the bilingual disadvantage arise during phonological encoding after competition for selection has already been resolved (Harley & Bown, 1998; Jescheniak & Levelt, 1994; Levelt, et al., 1999; Santesteban, et al., 2006). This is not necessarily a serious problem for the interference account provided that interactivity is allowed between languages and between phonological and lexical processing (e.g., Dijkstra &

Van Heuven, 2002; see Kroll & Dijkstra, 2002 for an extension of the BIA to production). Though note that once interactivity is adopted (e.g., Dell, 1986, 1990, 1997; MacKay, 1982; see review in Rapp & Goldrick, 2000) the interference account would then face the challenge of explaining any data which limit frequency effects to phonological encoding (e.g., frequency does not modulate competition for selection in the semantic blocking paradigm; Santesteban et al., 2006, and semantic substitution errors are also not frequency modulated (e.g., Garrett, 2001; Hotopf, 1980; but see Vitkovitch & Humphreys, 1991).

For Experiment 2 we predicted that the bilingual disadvantage should become smaller (in both languages) with increased age according to the weaker links account, but that the bilingual disadvantage should become larger (in both languages) with increased age according to the interference account. Results showed a smaller frequency effect in older adults than in younger adults in the nondominant language (supporting the weaker links account), but after adjusting for age-related slowing, there were no significant age-related changes in the size of the frequency effect in the dominant language. That is, even though the older bilinguals had been bilingual for many more years (56 more on average) than the younger bilinguals, there was no evidence that they were “catching up” to monolinguals for dominant language production, but there was evidence that access to the nondominant language was “catching up” to the dominant language but only for low-frequency names (within the bilinguals tested in Experiment 2 there was a significant three-way interaction between age, frequency, and language).

When naming pictures in the nondominant language (Spanish), older bilinguals named pictures with high-frequency names more slowly than younger bilinguals, but they named pictures with low-frequency names as quickly and accurately as younger bilinguals. Importantly, older bilinguals named pictures more quickly in English than in Spanish[5], and we matched younger and older bilinguals on a strict subject-by-subject basis for ability to translate (without time constraint) in both directions. Thus, it seems that older bilinguals accessed low-frequency words in their nondominant language relatively more quickly than would have been expected based on their own naming times for high-frequency words in the same language and, if age-related slowing were controlled, also relatively more easily than their younger counterparts. This finding is problematic for the interference account which predicted that language dominance effects should become larger with increased age which may impair the ability to control between-language interference (Hernandez & Kohnert, 1999), and that low-frequency words should be especially vulnerable to interference with increased age (which would be necessary to explain the results of Experiment 1; see also Spieler & Griffin, 2006).

Although the results for nondominant language production supported the weaker links hypothesis, the trends towards greater frequency effects in older adults (see also Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Balota & Ferraro, 1993, 1996; Chae et al., 2002; Spieler & Balota, 2000) are problematic for the weaker links account, and for activation based accounts of the frequency effect. Such models predict that frequency effects should become smaller as representations approach ceiling levels of activation. To explain why frequency effects do not seem to get smaller with increased age in monolingual language processing (Allen, et al., 1993; Balota & Ferraro, 1993, 1996; Bowles & Poon, 1981; Spieler & Balota, 2000; Tainturier, et al., 1989), it can be assumed that age influences lexical access in several ways that may offset each other differently depending on the task (see also Gollan & Brown, 2006; Spieler & Balota, 2000; Tainturier, et al., 1989). Even though there seemed

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[5] In some ways, the pattern of frequency effects in older bilinguals resembles what would be expected of bilinguals who use both languages equally often. Older bilinguals were clearly English dominant (in naming times, and ability to translate), but they demonstrated similarly sized frequency effects in English and in Spanish. Balanced bilinguals would be expected to show equivalent naming times and frequency effects in both languages, and larger frequency effects than matched monolinguals. The age-related increase in experience may allow older bilinguals to function more like balanced bilinguals in some respects. In future work it would be interesting to see if older bilinguals function like more balanced bilinguals in other respects.

to be no age-related slowing for producing low-frequency names in the nondominant language (see Figure 2) it would be odd to claim that age-related slowing applied only to the dominant language, and to high-frequency but not to low-frequency names in the nondominant language. Instead, what seems more likely is that older bilinguals produced low-frequency words in the nondominant language more easily than expected (based on their otherwise relatively slow naming times) because increased experience associated with increased age was especially powerful for counteracting age-related slowing in this case. That is, representations that were furthest from ceiling levels of activation (low-frequency words in the nondominant language) benefited most from additional use associated with increased age. This admittedly somewhat complex and speculative idea fits well with the finding that older monolinguals show a clear processing advantage (in terms of correct retrieval rates) relative to younger monolinguals for retrieving very low frequency words (e.g., *scythe*; Gollan & Brown, 2006). Complexity may simply be necessary for understanding age-effects which will likely entail positive and negative, as well as simply qualitative, differences.

Because the results of Experiment 2 could not easily be explained using either the combination of the weaker links and activation based accounts, or the interference account, it is interesting to consider whether an alternative mechanism provides a better explanation. For this purpose we consider the rank hypothesis which is qualitatively quite distinct from most other mechanisms of the frequency effect (Forster, 1992; Murray & Forster, 2004). According to the rank account, lexical access entails a search through a frequency ordered list. Within the search model access time is a function of lexicon size (not the absolute number of times that a word has been used) because access time is determined by the number of representations that must be considered as possible matches before the intended target is reached. This relationship between access time and lexicon size is particularly intriguing when considering the bilingual effect because the bilingual lexicon is much larger than the monolingual lexicon (see introduction).

Because the search model was developed to explain word recognition some modification is required to adapt it to language production. The motivation for a frequency ordered search was that nothing besides a string of letters can guide access to a unique memory location (i.e., “content addressability” is computationally unfeasible; Murray & Forster, 2004). But language production begins with conceptual processing, and as such it should be possible to limit candidates to those that are semantically related to the target (e.g., for the target *cup* the candidates might be *cup, glass, goblet, bowl, container*, *carafe*, *tank*, *tube*). Furthermore, it might be more logical to order a semantically driven list of candidates by degree of semantic fit with the intended target. To maintain the frequency ordered search, one could assume a dual-route process for arriving at the intended target. One list of candidates might be generated relatively slowly and precisely based on semantic fit with the target, whereas another frequency ordered list would be generated very rapidly and less precisely semantically (e.g., *stuff I use in the kitchen*). Candidates in the semantically precise list would then compete for selection (as proposed in many models of language production (e.g., Cutting & Ferreira, 1999; Harley, 1993; Howard, et al., 2006; Levelt et al., 1999; Lupker, 1979; Starreveld & La Heij, 1996; Stemberger, 1985; Wheeldon & Monsell, 1994), while the semantically general list is searched in order of most-frequent first. Subsequently, the competitive process could be aborted if the frequency ordered search list found the intended candidate first. On this view, the search process would be much more limited for production than for comprehension (and so frequency effects should be smaller in production than in comprehension; see also Garrett, 2001).

As noted above, the possibility of a search has some relevance for the present study. Concerning bilingual effects, the rank hypothesis provides a ready explanation for the increased magnitude of the frequency effect if it assumed that bilinguals must search longer lists than monolinguals (instead of an increased number of lists) to accommodate the roughly doubled lexicon size.

This is illustrated in Table 7 in which rank is also assigned without segregating representations into language specific lists. With this arrangement the rank distance between high- and low-frequency words is dramatically greater in bilinguals than in monolinguals because low-frequency words in the dominant language are ranked below high-frequency words in the nondominant language. To explain why the frequency effect was larger in the nondominant language in this “bilingual rank account” we assumed that low-frequency words in the nondominant language are at the very end of the search path (i.e., there is some degree of segregation between lexicons at the low end of the frequency scale). As such, in perfectly balanced bilinguals the frequency effect should be similarly sized in the two languages.

Another relevant difference between the rank hypothesis and activation based accounts is related to how the ceiling effect is implemented. In activation accounts some arbitrary limit must be imposed on the degree to which lexical representations can accumulate activation over time. The rank account captures the logarithmic nature of frequency of use and lexical accessibility in a more emergent way. To illustrate, according to the rank account, *car* is named about as quickly as *house* even though there is a very large difference in frequency count between these two words (*car* occurs 354/million, and *house* 607/million) because few words have such high frequency counts and therefore *car* and *house* have similar ranks. Note that low-frequency words can never “catch up” to high-frequency words because, unless speakers suddenly begin using low-frequency words much more often than they had before, their rank order will always remain lower than the higher-frequency words. For this reason, and because of the relative stability of vocabulary size throughout adulthood (for a review see Verhaegen, 2003), the rank hypothesis predicts (as we found) that the bilingual disadvantage should be relatively stable with increased age (frequency effects should also be stable with age; see discussion in Murray & Forster, 2004). In addition, the bilingual rank account (shown in Table 7) predicts that bilinguals should remain disadvantaged even if equated to monolinguals for degree of word use, whereas the activation account predicts that bilinguals should be able to catch-up to monolinguals (and not be disadvantaged) if they speak twice as much as monolinguals (and so use words as often as monolinguals; Gollan, Montoya, et al., 2005).

Although the rank hypothesis provides some compelling explanations of the bilingual effect and the failure of bilinguals to “catch up” to monolinguals with increased age for dominant language production, it faces the same challenges as discussed above for explaining why frequency effects attenuated with age in the nondominant but not in dominant languages. To achieve this result in Table 7, we effectively had to assume that older bilinguals were more balanced bilinguals than younger bilinguals (with similar ranks for both high- and low-frequency translation equivalents throughout the lexicon) which is a problem given that we matched young and older bilinguals for ability to translate. A way around this problem might be to assume that the absolute number of times a word is used can affect access time (even in a search based process) during an initial learning phase. Consistent with this notion, one study on picture naming accuracy showed larger frequency effects in adolescents and then stable frequency effects from young adulthood to older age (Newman & German, 2005). On this view, bilinguals remain in an “extended learning phase” throughout adulthood for the nondominant language. An intriguing broader implication of such a proposal is that there may be a limit on the extent to which the language system can handle a roughly doubled load at the lexical level. When the load is very big (in bilinguals), the process of accessing lexical representations may be qualitatively different in some respects than when the load is more limited (in monolinguals).

The discussion contrasting different mechanisms of the frequency effect in language processing models invites an elaboration of the weaker links hypothesis which is that whatever mechanism best explains the frequency effect in monolingual speakers, should also best explain the bilingual disadvantage in dominant language production relative to monolinguals. The name “weaker links” implies an activation metaphor but this may turn out not to be the most powerful one. A more general implication for models of bilingualism is that the analogy between bilingualism and frequency effects is more powerful than between-language competition for explaining the bilingual disadvantage on dominant language production. Interference effects may be more likely to arise during production in the less dominant language and in tasks that activate both languages more explicitly than picture naming (see review in Kroll et al., 2006). Note, however, that our failure to obtain significant slowing related to testing order in Experiment 1 (e.g., bilinguals who named pictures in the nondominant language first did not name pictures more slowly than bilinguals who named pictures in the dominant language first) suggests that robust interference effects might be observed only in tasks that require language mixing.

More generally still, the current results highlight the importance of frequency in models of lexical access and suggest that frequency effects “… are symptomatic of very basic properties of the human information retrieval system” (Murray & Forster, 2004, pp. 721). Relatively subtle differences in frequency of language use between bilinguals and monolinguals introduced robust differences in ability to access the lexicon (that were in some respects more powerful than, correlated variables such as AoA; contra Barry et al., 2001). Bilinguals displayed greater frequency effects in English even though the bilinguals were strongly English dominant, and had been immersed in an English-dominant environment for most (if not for all) of their lives. Because bilinguals and monolinguals likely share the same conceptual system (Francis, 2005; Kroll & Tokowicz, 2005), and because of interactions between frequency and length effects, our results also indirectly support the conclusion that frequency effects arise at a post-semantic locus where competition for selection has already been resolved (e.g., Jescheniak & Levelt, 1994).

Although we suggested that the results seem equally compatible (or incompatible) with the activation and rank mechanisms of the frequency effect, some common assumptions (that were necessary in both accounts for explaining the interaction between frequency and bilingualism and between frequency and language dominance) suggest some general conclusions about the nature of the frequency counter in the language system. First, it appears to be necessary to assume a ceiling on the degree to which increased use leads to increased accessibility. Second, and unique to the current study, frequency seems to be represented without consideration of rather obvious contextual constraints such as language membership. In other words, the frequency counter is powerful but profoundly ignorant.

In addition to the specific insights noted above, this work illustrates a valuable continuity between what are sometimes considered categorically different research domains. The fundamental premise supported in this research is that a phenomenon that typically would be attributed to a special problem exclusive to bilingual speakers (namely, competition between languages) seems instead to be caused by something that is relevant to cognitive processing more broadly (namely, frequency effects). More specifically, because frequency effects are relevant to monolingual and multilingual processing alike, this suggests that seemingly bilingual-only effects may be more language-general than originally thought. Similarly, by extending considerations of frequency effects to changes that occur across the lifespan, we gained insights about language representation, experience-dependent changes in cognitive processing, and the effects of aging on cognitive processing generally. Continued synergy between these seemingly distinct fields promises further unified scientific insights.

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Appendix

English Picture Name	Spanish Picture Name	list number	frequency category	CELEX ESL Noun Frequency per million
ghost	fantasma	1	HF	31.0
bell	campana	1	HF	41.6
tent	carpa	1	HF	43.9
knife	cuchillo	1	HF	44.2
chain	cadena	1	HF	48.6
ring	anillo	1	HF	49.1
suit	traje	1	HF	52.4
hat	gorro	1	HF	68.1
shoe	zapato	1	HF	79.2
eggs	huevos	1	HF	86.0
key	llave	1	HF	86.3

English Picture Name	Spanish Picture Name	list number	frequency category	CELEX ESL Noun Frequency per million
king	rey	1	HF	99.7
star	estrella	1	HF	100.8
box	caja	1	HF	102.6
ball	pelota	1	HF	111.5
bottle	botella	1	HF	116.2
sun	sol	1	HF	152.4
fish	pez	1	HF	163.5
heart	corazon	1	HF	164.1
butterfly	mariposa	1	HF	175.4
arm	brazo	1	HF	210.4
hand	mano	1	HF	725.3
lion	leon	2	HF	24.8
nail	clavo	2	HF	24.8
hook	anzuelo	2	HF	37.4
clock	reloj	2	HF	39.6
chicken	pollo	2	HF	41.0
matches	cerillo	2	HF	57.0
moon	luna	2	HF	59.1
coat	abrigo	2	HF	61.4
bridge	puente	2	HF	66.2
bone	hueso	2	HF	69.4
iron	plancha	2	HF	71.1
leaf	hoja	2	HF	81.1
dress	vestido	2	HF	87.3
ear	oreja	2	HF	87.7
tooth	diente	2	HF	87.9
gun	pistola	2	HF	98.9
bird	pajaro	2	HF	102.9
horse	caballo	2	HF	132.5
chair	silla	2	HF	136.4
baby	bebe	2	HF	258.1
car	coche	2	HF	354.3
house	casa	2	HF	606.9
bowl	tazon	3	HF	33.0
cow	vaca	3	HF	40.3
bomb	bomba	3	HF	41.2
stairs	escalones	3	HF	44.1
cat	gato	3	HF	66.8
bread	pan	3	HF	74.1
brain	cerebro	3	HF	74.9
nose	nariz	3	HF	81.2
dog	perro	3	HF	115.1
plant	planta	3	HF	121.2
newspaper	periodico	3	HF	121.6
finger	dedo	3	HF	123.6
glass	vaso	3	HF	145.0
tree	arbol	3	HF	191.7
window	ventana	3	HF	200.2
table	mesa	3	HF	235.1
bed	cama	3	HF	269.9
foot	pie	3	HF	327.2
door	puerta	3	HF	386.8
money	dinero	3	HF	403.7
book	libro	3	HF	434.6
eye	ojo	3	HF	524.3
steering	volante	1	LF	0.2
popcorn	palomitas	1	LF	0.8
braid	trenza	1	LF	1.5
mailbox	buzon	1	LF	1.8
peacock	pavoreal	1	LF	3.9
necklace	collar	1	LF	4.0
snail	caracol	1	LF	4.5
airplane	avion	1	LF	5.7
owl	buho	1	LF	7.2
cherry	cereza	1	LF	7.4
swan	cisne	1	LF	7.5
broom	escoba	1	LF	7.8
axe	hacha	1	LF	8.6
slippers	pantuflas	1	LF	8.8
apron	mandil	1	LF	9.2
slide	resbaladilla	1	LF	12.1

English Picture Name	Spanish Picture Name	list number	frequency category	CELEX ESL Noun Frequency per million
mushroom	hongo	1	LF	12.7
umbrella	paraguas	1	LF	13.7
knot	nudo	1	LF	14.0
bat	murcielago	1	LF	14.4
lock	candado	1	LF	15.5
bee	aveja	1	LF	16.7
blowdryer	secadora	2	LF	0.0
tire	llanta	2	LF	0.0
plunger	destapador	2	LF	0.6
octopus	pulpo	2	LF	1.5
dice	dado	2	LF	2.1
keyboard	teclado	2	LF	3.1
kite	papalote	2	LF	4.6
icecream	nieve	2	LF	4.9
strawberry	fresa	2	LF	6.4
puzzle	rompe cabeza	2	LF	8.7
whistle	silbato	2	LF	9.2
can	lata	2	LF	9.3
frog	rana	2	LF	9.4
crab	cangrejo	2	LF	9.5
leg	pierna	2	LF	10.2
purse	bolsa	2	LF	10.3
helmet	casco	2	LF	12.9
vacuum	aspiradora	2	LF	14.8
fork	tenedor	2	LF	14.9
drum	tambor	2	LF	15.8
pencil	lapiz	2	LF	18.6
crown	corona	2	LF	24.5
crutches	muletas	3	LF	0.0
dustpan	recogedor	3	LF	0.5
crib	cuna	3	LF	1.2
saw	serrucho	3	LF	1.5
hanger	gancho	3	LF	1.8
bathtub	tina	3	LF	1.9
pumpkin	calabaza	3	LF	2.1
lobster	langosta	3	LF	3.4
clown	payaso	3	LF	3.6
comb	peine	3	LF	5.4
garlic	ajo	3	LF	6.4
rainbow	arcoiris	3	LF	6.8
carrot	zanahoria	3	LF	8.0
windmill	molino	3	LF	8.9
badge	placa	3	LF	9.2
grapes	uvas	3	LF	10.0
hammer	martillo	3	LF	11.0
ant	hormiga	3	LF	11.7
scarf	bufanda	3	LF	12.2
spoon	cuchara	3	LF	15.4
button	boton	3	LF	26.2
cheese	queso	3	LF	30.6

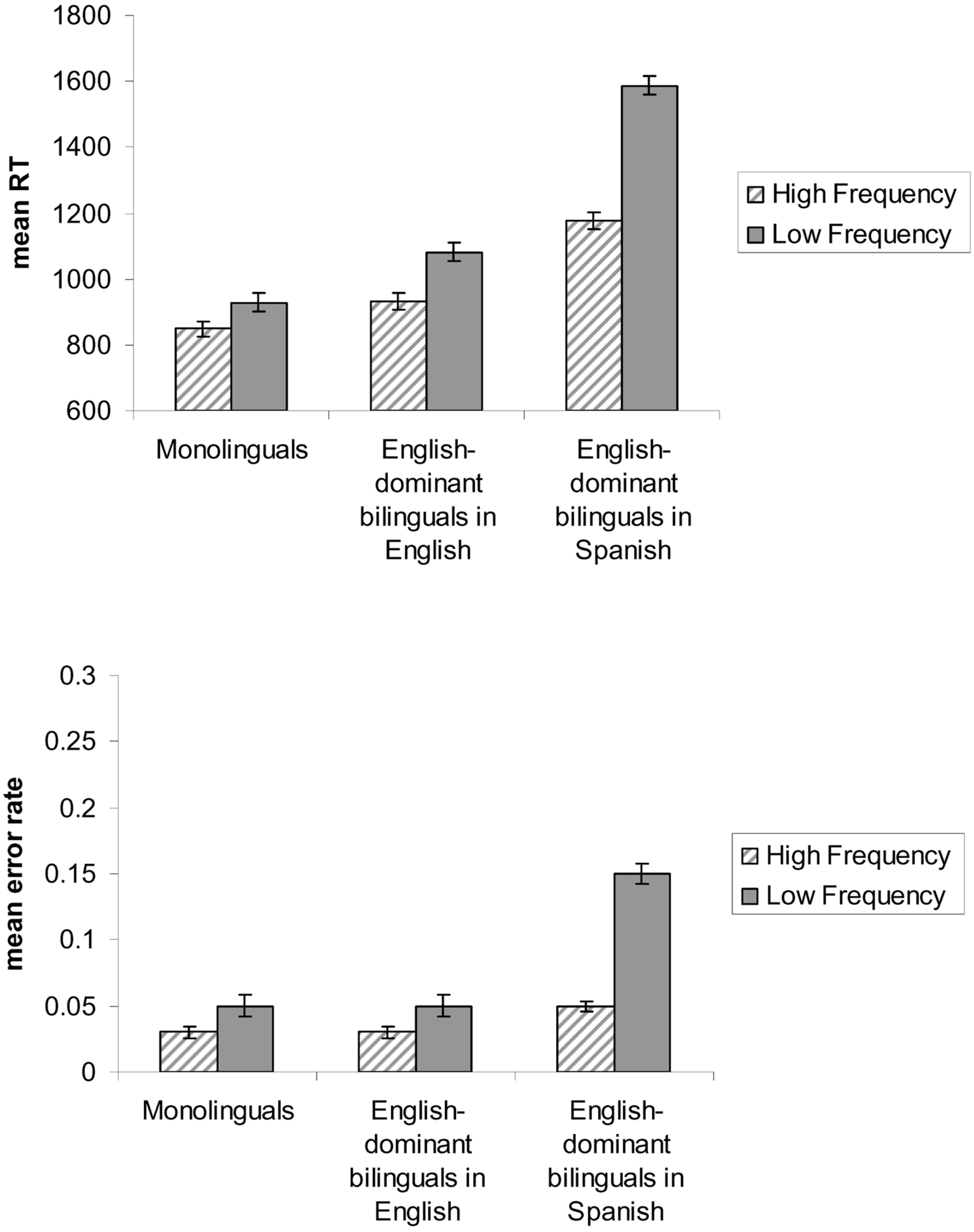

Figure 1.

Mean picture naming reaction times (top panel; in milliseconds) and error rates (bottom panel) for English dominant bilinguals (n=57) and monolinguals (n=57) tested in English and Spanish (for bilinguals only) in Experiment 1. Error bars show the standard error of the mean.

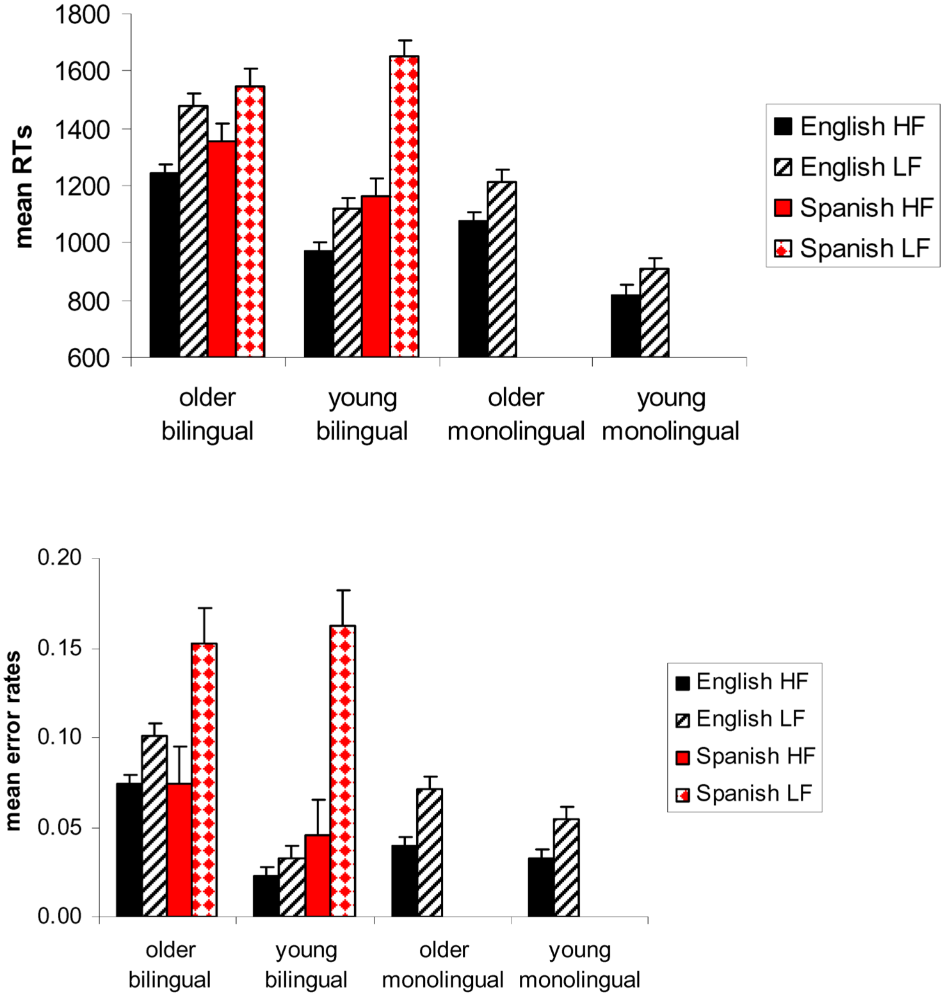

Figure 2.

Mean picture naming reaction times (top panel; in milliseconds) and error rates (bottom panel) for older (n=14) and young (n=14) English-dominant bilinguals and for older (n=14) and young (n=14) monolinguals tested in Experiment 2. Error bars show the standard error of the subject means by frequency category.

Table 1

Baseline activation levels for young and older bilinguals and monolinguals in a model with selection threshold set at 6. Increased age, monolingualism, and language dominance were assumed to entail increased use. For age effects, activation levels were promoted upwards by 5% of distance from threshold for each additional decade of life. Bilingual effects were introduced by adjusting bilinguals' dominant-language activation levels downwards (by 5% of distance from threshold) from monolinguals' activation level. Language dominance effects were introduced by adjusting nondominant-language activation levels downwards (by 5% of distance from threshold) from dominant-language activation level. Over time (with age) frequency effects, bilingual effects, and language dominance effects decrease because representations approach ceiling. Note that the predicted "frequency effects" were measured using words all subjects should know (i.e., glass minus pitcher, excluding words like cruet which young adults and bilinguals might not know; Gollan & Brown, 2006) because the use of words that are not well established for one group of participants could inflate frequency effects in that group (Murray & Forster, 2004).

	Word	**baseline activation at 20 years old**	**baseline activation at 70 years old**
Monolingual lexicon	glass	5.00	5.23
	cup	4.00	4.45
	jar	3.00	3.68
	container	2.00	2.90
	pitcher	1.00	2.13
	goblet	not known	1.36
	cruet	not known	1.36
	frequency effect	*4.00*	*3.10*
Bilingual dominant language lexicon	glass	4.95	5.19
	cup	3.90	4.38
	jar	2.85	3.56
	container	1.80	2.75
	pitcher	0.75	1.94
	goblet	not known	1.13
	cruet	not known	1.13
	frequency effect	*4.20*	*3.25*
Bilingual nondominant language lexicon	vaso	4.90	5.15
	taza	3.80	4.29
	frasco	2.69	3.44
	contenedor	1.59	2.59
	jarra	0.49	1.73
	copa	not known	0.88
	vinagrera	not known	0.88
	frequency effect	*4.41*	*3.41*

Table 2

Average and standard deviation of participant characteristics for Experiment 1.

Characteristic	**Spanish-English Bilinguals (n=57)**		**Monolinguals (n=57)**	
	M	**SD**	**M**	**SD**
Age	20.0	2.5	20.5	3.7
Education	13.8	1.9	14.3	1.1
Percent translated into English	82.0	8.4	--	--
Percent translated into Spanish (or other language for monolinguals)	67.0	12.4	16.2	11.8
Percent daily use of English	88.1	11.4	99.4	1.9
Age of exposure to English	2.3	2.4	0.2	0.5
English self-rated speaking[a]	6.8	0.5	7.0	0.1
Age of exposure to other language	0.5	1.5	10.2	5.5
Other language self-rated speaking[a]	5.7	1.3	3.0	1.3

[a] Proficiency level based on self-ratings using a scale of 1–7 with 1 being “little to no knowledge” and 7 being “like a native speaker.”

Table 3

Average and standard deviation of picture name characteristics for each list in Experiments 1 & 2.

Characteristic	**List 1**				**List 2**				**List 3**			
	HF (n=22)		**LF (n=22)**		**HF (n=22)**		**LF (n=22)**		**HF (n=22)**		**LF (n=22)**	
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
English frequency	125.1	143.1	8.1	5.0	117.5	133.3	8.7	6.5	184.3	146.1	8.1	7.9
English frequency range	31 – 725.3		0.2 – 16.7		24.8 – 606.9		0 – 24.5		0 – 30.6		33 – 524.3	
English length in phonemes	3.3	1.0	4.5	1.5	3.4	0.7	4.7	1.6	3.7	1.6	4.7	1.4
Spanish frequency	51.8	87.5	3.3	4.2	52.9	132.2	16.3	36.8	79.2	76.9	4.1	4.3
Spanish length in phonemes	5.3	1.5	6.3	2.1	5.1	1.2	6.4	2.0	5.1	1.7	6.0	1.6

Table 4

Average (and standard deviation) AoA ratings of high and low frequency picture names used in Experiments 1 and 2.

Participant Type	Language	High Frequency (n=66)		Low Frequency (n=66)	
		Mean	**SD**	**Mean**	**SD**
Monolinguals Bilinguals	English	3.6	0.8	4.4	1.0
	English	5.1	1.0	6.2	1.4
	Spanish	4.3	1.6	5.9	2.0

Table 5

Average and standard deviations of participant characteristics for Experiment 2.

Characteristic	Young Spanish-English Bilinguals		Older Spanish-English Bilinguals		Young Monolinguals		Older Monolinguals	
	M	SD	M	SD	M	SD	M	SD
Age	19.3	1.3	74.9	7.4	19.3	1.0	76.0	6.6
Education	13.4	1.1	13.3	2.3	13.9	1.0	14.1	2.8
Percent translated into English	85.2	6.5	85.1	8.7	--	--	--	--
Percent translated into Spanish (or other language for monolinguals)	75.2	12.5	76.5	14.0	31.2	11.5	18.5	22.4
Percent daily use of English	80.3	21.7	67.5	29.9	99.8	0.6	100.0	--
Age of exposure to English	2.7	3.3	4.6	5.4	0.2	0.4	0	--
English self-rated speaking[a]	6.8	0.6	5.6	1.1	6.9	0.3	6.5	0.9
Age of exposure to other language	1.2	2.7	0	0	6.2	5.5	14.1	14.1
Other language self-rated speaking[a]	5.7	1.3	4.9	1.0	2.9	1.5	1.6	0.7
Dementia Rating Scale Score	--	--	133.6	5.7	--	--	138.6	4.3
Mini Mental Status Exam Score	--	--	29.1	1.5	--	--	28.9	0.9

[a] Proficiency level based on self-ratings using a scale of 1-7 with 1 being “little to no knowledge” and 7 being “like a native speaker.”

Table 6

Two-tailed t-tests comparing bilinguals to monolinguals within the young and older participant groups, and comparing young to older participants within the bilingual and monolingual groups in Experiment 2. The df = 26 for all comparisons.

Characteristic	Within Young Bilinguals versus Monolinguals	Within Older Bilinguals versus Monolinguals	Within Bilinguals Young versus older	Within Monolinguals Young versus older
Age	t < 1	t < 1	p < .01	p < .01
Education	p = .26	t < 1	t < 1	t < 1
Percent translated into English	NA	NA	t < 1	NA
Percent translated into Spanish (or other language for monolinguals)	p < .01	p < .01	t < 1	p = .11
Percent daily use of English	p < .01	p < .01	p = .21	p = .18
Age of exposure to English	p = .01	p < .01	p = .26	p = .07
English self-rated speaking[a]	t < 1	p = .04	p < .01	p = .08
Age of exposure to other language	p = .01	p < .01	p = .09	p = .07
Other language self-rated speaking[a]	p < .01	p < .01	p = .11	p = .01
Dementia Rating Scale Score	NA	p = .02	NA	NA
Mini Mental Status Exam Score	NA	t < 1	NA	NA

Table 7

Example ranks for lexical representations of high- and low-frequency picture names in young and older monolinguals, and young and older bilinguals in the dominant and nondominant languages. Rank is assigned based on frequency of use without considering language membership. The size of the frequency effect remains relatively stable with increased age in monolinguals because age improves vocabulary only at the very low-frequency end of the lexicon. Frequency effects are larger in bilinguals relative to monolinguals because the rank distance between high- and low-frequency words within each language is increased by words in the other language. Young bilinguals show bigger frequency effects in the nondominant language because low-frequency words in the nondominant language are at the end of the search path (see Experiments 1 and 2). Older bilinguals are shown to have a more balanced pattern of similarly sized frequency effects in both languages (as found for older adults in Experiment 2).

subject type	**Word**	**rank at 20 years old**	**rank at 70 years old**
monolingual lexicon	glass	1	1
	cup	2	2
	jar	3	3
	container	4	4
	pitcher	5	5
	goblet	not known	6
	cruet	not known	7
	frequency effect	*4.00*	*4.00*
bilingual dominant language lexicon	glass	1	1
	cup	3	3
	jar	5	5
	container	6	7
	pitcher	7	9
	goblet	not known	11
	cruet	not known	13
	frequency effect	*6.00*	*8.00*
bilingual nondominant language lexicon	vaso	2	2
	taza	4	4
	frasco	8	6
	contenedor	9	8
	jarra	10	10
	copa	not known	12
vinagrera	not known	14	
	frequency effect	*8.00*	*8.00*