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Cognitive consequences of trilingualism

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Abstract

Aims and objectives: The objectives of the present research were to examine the cognitive consequences of trilingualism and explain them relative to the cognitive consequences of bilingualism.

Approach: A comparison of cognitive abilities in trilinguals and bilinguals was conducted. In addition, we proposed a cognitive plasticity framework to account for cognitive differences and similarities between trilinguals and bilinguals.

Data and analysis: Three aspects of cognition were analyzed: (1) cognitive reserve in older adults, as measured by age of onset of Alzheimer's disease and mild cognitive impairment; (2) inhibitory control in children and younger adults, as measured by response times on behavioral Simon and flanker tasks; and (3) memory generalization in infants and toddlers, as measured by accuracy on behavioral deferred imitation tasks. Results were considered within a framework of cognitive plasticity, which took into account several factors that may affect plasticity including the age of learning a third language and the extent to which additional cognitive resources are needed to learn the third language.

Findings: A mixed pattern of results was observed. In some cases, such as cognitive reserve in older adults, trilinguals showed larger advantages than did bilinguals. On other measures, for example inhibitory control in children and younger adults, trilinguals were found to exhibit the same advantages as bilinguals. In still other cases, such as memory generalization in infants and toddlers, trilinguals did not demonstrate the advantages seen in bilinguals.

Originality: This study is the first comprehensive analysis of how learning a third language affects the cognitive abilities that are modified by bilingual experience, and the first to propose a cognitive plasticity framework that can explain and predict trilingual-bilingual differences.

Significance: This research shows that the cognitive consequences of trilingualism are not simply an extension of bilingualism's effects; rather, trilingualism has distinct consequences, with theoretical implications for our understanding of linguistic and cognitive processes and their plasticity, as well as applied-science implications for using second and third language learning in educational and rehabilitative contexts to foster successful cognitive development and aging.

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Introduction

Some expert language learners, called hyperpolyglots, achieve the rare feat of mastering 10 languages or more. For example, famous hyperpolyglot Emil Krebs (1867–1930), a German who worked as interpreter in China, became proficient in more than 65 languages, including uncommon languages such as Nivkh and Ainu (Amunts, Schleicher, & Zilles, 2004; Erard, 2012). While extreme multilingualism, as in Kreb's case, is rare, multilingualism is not; in fact, in some parts of the world, speaking three languages is the norm. For instance, in the country of Mauritius, off the coast of Africa, most people are trilingual in Mauritian Creole, English, and French (Braun & Cline, 2014). Likewise, in Luxembourg in Europe, most people speak Luxembourgish, French, and German (Braun & Cline, 2014).

Despite its prevalence, research on trilingualism has been limited relative to research on bilingualism. The large body of bilingualism research has revealed several cognitive consequences of knowing two languages, including advantages in executive functioning, learning, and memory, as well as disadvantages in language production (for reviews, see Adesope, Lavin, Thompson, & Ungerleider, 2010; Bialystok, Craik, Green, & Gollan, 2009). Effects of bilingualism have been observed across the lifespan (from infancy to older age) with speakers of many different languages (from Spanish-Catalan bilinguals to Dutch-Frisian bilinguals) on a variety of tasks (including Stroop, Simon, and flanker tasks) in laboratories across the world (including India, Canada, and Spain) (Alladi et al., 2013; Bialystok, Craik, & Luk, 2008; Costa, Hernández, & Sebastián-Gallés, 2008; Craik, Bialystok, & Freedman, 2010; Hernández, Costa, Fuentes, Vivas, & Sebastián-Gallés, 2010; Houtzager, Lowie, Sprenger, & de Bot, in press; Kovács & Mehler, 2009; Luo, Craik, Moreno, & Bialystok, 2013; Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012).[1]

While still much smaller than the body of bilingualism research, research on the cognitive consequences of trilingualism is increasing (Chertkow et al., 2010; Kavé, Eyal, Shorek, & Cohen-Mansfield, 2008). The effects of trilingualism are important to document (beyond bilingual effects) for a few reasons. One is that developing accurate and comprehensive models of the mind requires characterizing the cognitive profiles of prevalent subsets of the population; trilinguals constitute a large part of the world's population and are even the norm in some countries (Braun & Cline, 2014). Furthermore, determining whether trilingual cognitive advantages are stronger than bilingual cognitive advantages has theoretical implications for our understanding of cognitive plasticity and the brain's potential degree of change. It also has practical implications for educational programs. Trilingual education is used in certain countries, such as Germany, in which students study English and French in addition to German. Because bilingual education is often recommended on the basis of its purported cognitive advantages (Christoffels, de Haan, Steenbergen, van den Wildenberg, & Colzato, 2014; Marian, Shook, & Schroeder, 2013), trilingual education may be advocated for on the basis of potentially providing even greater advantages. Here, we review trilingual cognitive performance relative to bilingual cognitive performance. Specifically, we discuss whether becoming trilingual increases the bilingual advantages in inhibitory control, memory generalization, and cognitive reserve.

In reviewing these cognitive advantages, we use a supply–demand framework of experience-dependent plasticity in which bi- and trilingualism are viewed as forms of mental training.

A supply–demand cognitive plasticity framework of bilingual and trilingual advantages

There is now compelling evidence that components of cognitive functioning can be improved by participating in certain activities, including playing action video games (Green & Bavelier, 2006), performing meditative practices (Lutz, Slagter, Dunne, & Davidson, 2008), and playing a musical instrument (Schellenberg, 2005). Improvements from these activities occur, according to the *supply–demand mismatch* hypothesis, because the *demand* imposed on a cognitive process (i.e. the level of cognitive resources required) is higher than the currently available *supply* of cognitive resources (Lindenberger, 2014; Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010). When the supply is below the demand, the cognitive system attempts to adapt by increasing the supply and, with several repetitions, a more enduring increase in the supply occurs (i.e. an improvement in the cognitive function). In other words, improvements in a cognitive process manifest when a person is repeatedly faced with a challenging task. In the case of playing action video games, visual perception and attention are frequently taxed, leading to improvements on visuospatial processing tasks (Green & Bavelier, 2003). During meditation, demands are consistently placed on focused and sustained attention, resulting in enhancements in executive control skills (Tang et al., 2007). When playing an instrument, a musician constantly encounters the difficult task of coordinating auditory, visual, and sensorimotor processes, leading to gains in multi-sensory integration and executive functions (Petrini et al., 2009; Schellenberg, 2005; Schroeder, Marian, Shook, & Bartolotti, in press).

Bilingualism is similar to these experiences in that it places increased demands on certain aspects of cognition, including processes related to inhibitory control, memory generalization, and cognitive reserve. For inhibitory control (the ability to ignore irrelevant information), bilinguals face higher demands than monolinguals because of the need to prevent interference from a second, non-target language when using a target language (Blumenfeld & Marian, 2011; Green, 1998). These higher demands may lead to a supply increase in inhibition for bilingual children, younger adults, and older adults (Bialystok, Craik, Klein, & Viswanathan, 2004; Carlson & Meltzoff, 2008; Costa, Hernández, & Sebastián-Gallés, 2008). Bilingualism also places an increased burden on memory processes; while both monolinguals and bilinguals have to encode, store, and retrieve linguistic information (such as words and grammatical rules), the amount of information is larger for bilinguals. Moreover, while both monolinguals and bilinguals often have to retrieve information that was encoded in a different spatial or temporal context, bilinguals sometimes have to retrieve information that was encoded in a different spatial, temporal, *and linguistic* context (Marian & Fausey, 2006; Marian & Neisser, 2000). These memory demands may contribute to bilingual infants and toddlers' increased memory generalization performance (i.e. the ability to apply knowledge to a different context) (Brito & Barr, 2012). Furthermore, the supply increases in inhibitory control and memory processes may underlie bilingual older adults' increased cognitive reserve, which enables them to better cope with age-related declines in cognitive processing (Bialystok, Craik, & Freedman, 2007; Craik, Bialystok, & Freedman, 2010; Schroeder & Marian, 2012).

Within this supply–demand framework, trilingual experience may be thought of as imposing a higher level of cognitive demands than bilingualism. For example, relative to a bilingual, a trilingual has to remember even more words and has to inhibit even more languages. To adapt to this increase in cognitive demands, trilinguals may develop a larger cognitive supply (i.e. greater advantages) than do bilinguals. The greater advantages may be most evident in trilinguals who add their second and third languages sequentially (rather than simultaneously). In sequential trilinguals, the increase in demands occurs gradually as the person advances from two languages to

three languages (rather than the suddenly large increase in demands faced by simultaneous second-and-third language learners). A gradual, step-wise rise in difficulty is a principle used in many cognitive training paradigms (Anguera et al., 2013; Holmes, Gathercole, & Dunning, 2009). It is also an inherent feature of video-game playing (video gamers advance from easier to more difficult levels of a game), music performance (musicians proceed to more challenging musical compositions only after mastering simple compositions), and meditation practice (meditators use more nuanced techniques once they have sufficient practice with the basic techniques) (Green & Bavelier, 2008; Slagter, Davidson, & Lutz, 2011). A gradual increase in demands is conducive to increasing the supply because the demands are encountered in smaller, more manageable chunks; in other words, the demands are never too much higher than the supply. Thus, the gradual increase in demands faced by sequential second-to-third language learners may be ideal for increasing cognitive gains.

However, apparent increases in cognitive demands do not always lead to a larger supply (Chooi & Thompson, 2012; Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Shipstead, Hicks, & Engle, 2012), and by extension, trilingualism may not always produce stronger gains than bilingualism. The following scenarios describe conditions under which there may *not* be additional gains in trilinguals.

First, if trilingualism does not actually increase the demands for a cognitive process, then further gains may not be observed. Indeed, some of the demands of bilingualism may arise from moving beyond a one-language system to a multi-language system, regardless of the number of languages, and thus adding a third language may not increase the difficulty (and, consequently, may not increase the gains).

Furthermore, if trilingualism increases the cognitive demands, but the level is too high relative to the supply, additional gains may still not be observed. When there is a large difference between supply and demand, the task becomes too challenging and cognitive gains are not observed (Jaeggi et al., 2011; Slagter, Davidson, & Lutz, 2011). This may be the case for some trilinguals who learn their second and third languages simultaneously. While sequential second-to-third language learners face a gradual increase in demands, simultaneous learners face a steep change. This large increase in demands may be especially difficult to contend with if the supply is really low (for example, in infants and toddlers). With a large gap between supply and demand, simultaneous trilingual infants and toddlers may not develop even the same gains as bilinguals, as high difficulty tasks can lead participants to give up on a task or to use alternative mechanisms to complete the task (Lövdén et al., 2010).

(Note that despite the large gap between supply and demand, infants and toddlers are still able to learn a third language for three reasons. First, the supply and demand that is relevant to the specific cognitive advantage may be outside of the language system. For example, the supply and demand may relate to remembering *non-linguistic* information in the face of changes in linguistic context (see 'Too much of a good thing' section for a detailed discussion); in this case, language learning would not be impeded. Second, if the relevant supply and demand are related to language learning, infants and toddlers may still be able to effectively learn a third language by recruiting alternative mechanisms. For instance, when learning a third language, infants and toddlers may overly rely on frontal executive processes to accomplish a task that is normally done through temporal lobe processes. Even if the alternative mechanisms do not compensate enough to enable efficient language learning, infants and toddlers will still be able to learn a third language when their supply increases through normal cognitive development.)

Even if the demands are increased to a level that is not too high (and not too low), further gains in trilinguals may still not be observed. This may be the case if the person's supply is too close to their ceiling level, such as in younger adults relative to older adults (see Bialystok,

Martin, & Viswanathan, 2005, and Valian, 2015, for relevant discussion). Biological constraints likely prevent unlimited improvement, and there may be a high capacity level that is less amenable to further plasticity.

Yet another situation in which increased trilingual demands may fail to elicit increased gains is when the supply is already higher than the demands. If there is a significant amount of time between acquiring a second language and a third language, then before third language acquisition, other experiences (e.g. meditation, video game playing, musicianship, etc.) may have already increased the supply above the demands of trilingualism; in this case, the person is not challenged to increase their supply.

There are thus multiple scenarios for how trilingualism may affect the cognitive processes that are enhanced through bilingualism. According to some scenarios, trilingualism may increase certain bilingual advantages. Indeed, there is some initial evidence that trilingual older adults may show larger gains than bilingual older adults in cognitive reserve (Chertkow et al., 2010; Perquin et al., 2013). Based on other scenarios, trilingualism may fail to increase some bilingual advantages. Consistent with these scenarios, preliminary research suggests that trilingual children and younger adults may perform at the same level as their bilingual peers in inhibitory control (Poarch & Bialystok, 2015; Vega-Mendoza, West, Sorace, & Bak, 2015). In yet another scenario, trilingualism may not only fail to increase some bilingual advantages, but may even fail to elicit the advantages observed in bilinguals. In line with this scenario, some recent studies suggest that trilingual infants and toddlers may not develop the same benefits as their bilingual peers in memory generalization tasks (Brito, Grenell, & Barr, 2014; Brito, Sebastián-Gallés & Barr, 2015). We now consider each of these cases in more depth.

The more, the merrier: trilingualism increases the bilingual advantage in cognitive reserve in older adults

Bilingual older adults have been shown to exhibit an increased level of cognitive reserve, which enables them to better maintain mental faculties in spite of age-related declines (Abutalebi et al., 2015; Gold, Johnson, & Powell, 2013). As evidence, several studies have shown that bilingualism delays the onset of memory symptoms in Alzheimer's disease by about four or five years. In the first study on this topic, Bialystok, Craik, and Freedman (2007) assessed the hospital records of 184 dementia patients in Toronto, Canada, half of whom were bilingual. Records indicated that the age of symptom onset was 75.5 years old for bilinguals and 71.4 years old for monolinguals (a 4.1 year difference). In replication, Craik, Bialystok, and Freedman (2010) examined a new set of patients and observed a delay of 5.1 years in bilinguals relative to monolinguals (for replications, see Alladi et al., 2013; Gollan, Salmon, Montoya, & Galasko, 2011; Woumans, et al., 2015; for replication failures, see Chertkow et al., 2010; Lawton, Gasquoine, & Weimer, 2014).

In addition to delaying the onset of Alzheimer's symptoms, bilingualism also delays the onset of symptoms in amnestic mild cognitive impairment, a precursor to Alzheimer's dementia. In a study assessing age of mild cognitive impairment onset, bilinguals were found to have a 4.5-year delay relative to monolinguals (Ossher, Bialystok, Craik, Murphy, & Troyer, 2013). Both the delay in mild cognitive impairment and in Alzheimer's disease were later replicated in the same study, with bilinguals showing mild cognitive impairment symptoms at 66.9 years compared to monolinguals at 62.2 years, and with bilinguals showing Alzheimer's symptoms at 78.2 years compared to monolinguals at 70.9 years (Bialystok, Craik, Binns, Ossher, & Freedman, 2014).

Increased cognitive reserve in bilingual older adults has been attributed to enhanced executive functioning (Gold, Johnson, & Powell, 2013; Ossher et al., 2013). Several executive processes are required for bilingual language processing, such as 'inhibition' for ignoring the irrelevant

language, 'monitoring' for supervising which language(s) are currently relevant, and 'switching' for shifting from the irrelevant language to the relevant language. Resulting from these demands, bilingual older adults exhibit less deterioration of frontal brain regions and, correspondingly, higher executive abilities than monolingual older adults (Bialystok et al., 2004; Grady, Luk, Craik, & Bialystok, 2015; Olsen et al., 2015). With better executive abilities, bilinguals may be more effective at engaging in the encoding and retrieval processes that support memory performance (Schroeder & Marian, 2012). That is, bilinguals may be able to use frontal-based executive functions for what is called "working-with-memory," an effortful, controlled process that, for example, may enable recovery of hard-to-access memories in older adults who have deterioration in the medial temporal memory system (Bouazzaoui et al., 2014; Moscovitch, 1992). These frontal-based executive functions used for retrieving hard-to-access memories may be further exercised in bilinguals because of the frequent need to recall information that was encoded in a different language, a situation that can decrease access to memories and make retrieval more demanding (Marian & Fausey, 2006; Marian & Neisser, 2000).

In addition to exercising frontal-based executive processes that contribute to memory performance, bilingualism may also tax parietal- and temporal-based memory processes. Bilinguals have to encode, store, and retrieve more lexical entries and lexical-semantic mappings than monolinguals. These efforts may contribute to better neural preservation for bilingual older adults in both the inferior parietal lobule and the anterior temporal lobe (Abutalebi et al., 2014, Abutalebi et al., 2015; Della Rosa et al., 2013; Mechelli et al., 2004). Bilingualism may thus increase functioning in frontal, temporal, and parietal processes that underlie memory performance, together creating a high degree of cognitive reserve.

It is possible that trilinguals develop even more cognitive reserve than do bilinguals. However, for these additional gains to manifest, trilingual demands need to be higher than the bilingual demands (and higher than the person's supply), but not excessively high. Cognitive reserve in trilingual older adults may meet these criteria. The trilingual demands may be higher than bilingual demands for at least some of the many processes that may contribute to bilingual cognitive reserve (i.e. frontal-based processes, such as inhibition, monitoring, or switching, or temporal- or parietal-based processes). The trilingual demands are also likely to be higher than the supply in old age, because even if other experiences during childhood, young adulthood, and middle age increase the supply beyond the trilingual demands, age-related declines will eventually drop the supply below the demands. Moreover, the trilingual demands are unlikely to be too high, regardless of whether the person acquires the second and third languages simultaneously or sequentially. If the second and third languages are learned sequentially, the demands will be gradually increased (and therefore potentially manageable). If the second and third languages are learned simultaneously and early in life, the large jump in demand may still be manageable because of a high supply in young adulthood and middle age. For these reasons, cognitive reserve is a good candidate for additional gains in trilinguals.

To test whether cognitive reserve is further increased in trilinguals, Chertkow et al. (2010) compared the onset of Alzheimer's disease in multilinguals, bilinguals, and monolinguals using records from 632 patients who visited a memory clinic in Montreal, Canada. Records indicated that the patients who were trilingual had been diagnosed marginally later than had bilingual patients (78.6 years for trilinguals versus 76.7 years for bilinguals). This analysis suggests that trilingualism may delay the onset of Alzheimer's more than bilingualism, indicative of an additional gain in cognitive reserve for trilinguals (but see Alladi et al., 2013, for a failure to replicate in an Indian population).

If trilingualism increases cognitive reserve more than bilingualism, then trilinguals should not only have more protection against Alzheimer's disease, but they should also have more protection

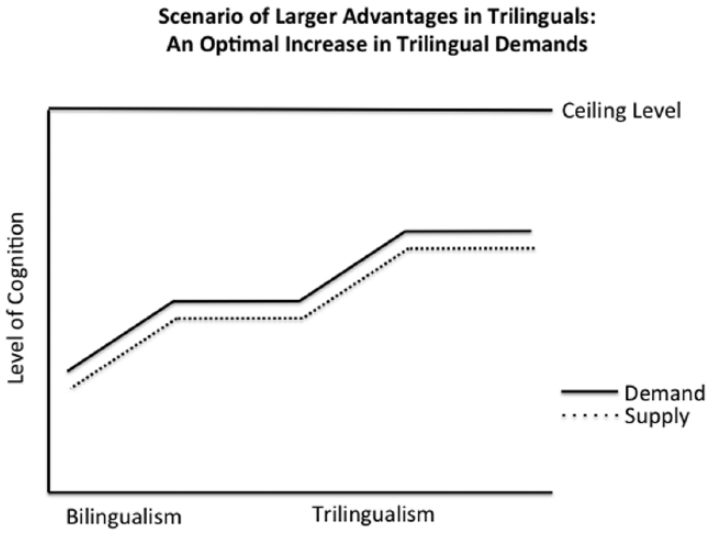

Figure 1. A scenario in which trilinguals would demonstrate larger cognitive advantages than bilinguals. In this scenario, the demands increase when transitioning from two languages (bilingualism) to three languages (trilingualism). To meet these demands, there is a corresponding increase in the supply (i.e. a further enhancement in the cognitive process).

against mild cognitive impairment, the precursor to Alzheimer's disease. To test this possibility, Perquin et al. (2013) assessed 232 older adults (mean age of 72.5) who were living in Luxembourg and were either bilingual or multilingual. Older adults' cognitive function was assessed with standard neuropsychological tests to determine which participants qualified as mildly cognitive impaired (referred to as Cognitive Impairment Without Dementia). Results revealed that trilinguals were significantly less likely than bilinguals to have mild cognitive impairment.

Preliminary research therefore suggests that trilingualism may increase cognitive reserve to an even greater extent than bilingualism, though more research is needed to confirm this trend (see Kavé, Eyal, Shorek, & Cohen-Mansfield, 2008, for additional evidence). This increased reserve may develop because of the higher demands of trilingual processing (relative to bilingual processing), which, in turn, leads to a higher supply. This process is illustrated in Figure 1, with a sequential bilingual-to-trilingual facing a higher level of demands that is reached through an increased supply. While initial evidence for increased reserve in trilinguals has been found, further research is needed to confirm this finding. As has been pointed out, there is a concern of self-selection biases in trilingualism research (Bialystok, Craik, & Luk, 2012; Kavé et al., 2008). In other words, it is possible that many people who become trilingual are advantaged at the outset. Another potential confounding variable in some of these studies is the immigrant status of many of the bilinguals and trilinguals (Bialystok, Craik, & Freedman, 2007; Craik, Bialystok, & Freedman, 2010). While potentially a contributing factor (Fuller-Thomson & Kuh, 2014), immigrant status does not seem to fully account for the bilingual and trilingual advantages, as the advantages are still observed in non-immigrant populations (Alladi et al, 2013; Schweizer, Craik, & Bialystok, 2013).

If the results are confirmed in additional studies that eliminate the confounds of self-selection and immigration, then further research should examine precisely why trilinguals show larger gains than bilinguals. We suggest that trilingualism increases demands on executive processes because of the need to inhibit, monitor, and switch among more languages, and/or increases demands on

memory processes because of the need to encode, store, and retrieve more linguistic information; these demands would lead to an increase in cognitive reserve, which, in turn, would allow memory to be maintained despite normal and pathological aging. To begin to assess this hypothesis, future behavioral studies should compare trilingual older adults to their bilingual counterparts on memory and executive functions, similar to previous work that has compared bilinguals to monolinguals on these measures (Bialystok et al., 2004; Schroeder & Marian, 2012; Wodniecka, Craik, Luo, & Bialystok, 2010).

More of the same: trilingualism does not change the bilingual inhibitory control advantage in children and young adults

The most thoroughly researched cognitive effects of bilingualism are in inhibitory control, the ability to ignore irrelevant information and attend to relevant information. Bilingualism places demands on inhibitory control that are above those faced by monolinguals. For example, when hearing a word in English (e.g. "marker"), both English-Spanish bilinguals and English monolinguals mentally access other English words that initially sound similar to the target word (e.g. marble, martini, martyr); these words can interfere with processing and thus need to be inhibited (Blumenfeld & Marian, 2011; Blumenfeld, Schroeder, Bobb, Freeman, & Marian, in press). Bilinguals face additional inhibitory demands, however, because they also access words in their other language. For example, an English-Spanish bilingual also accesses *mariposas* (the word for butterfly) and *mariscada* (the word for seafood platter) when hearing the word "marker" (Blumenfeld & Marian, 2013). This cross-linguistic activation occurs not only during comprehension but also during production (Green, 1998). To meet the high inhibitory demands during both comprehension and production, bilinguals need to develop strong inhibitory mechanisms. Accordingly, bilingual children, younger adults, and older adults develop enhanced inhibitory control relative to monolinguals, as evidenced by superior performance across several non-linguistic assessments of cognitive control (Adesope et al., 2010; Bialystok, Craik, Green, & Gollan, 2009; but for replication failures, see Morton & Harper, 2007; Paap & Greenberg, 2013).

For example, Costa, Hernández, & Sebastián-Gallés (2008) tested monolingual and bilingual younger adults on a flanker task. In this task, participants see a row of arrows (e.g. > > > > >) and have to indicate the direction of the center arrow. On some trials, the center arrow goes in the opposite direction of the flanker arrows (e.g. > > < > >), making participants slower to respond to the direction of the center arrow. Bilinguals were less slowed by the incongruent flanker arrows than monolinguals, presumably because they were better at inhibiting the flanker arrows and focusing on the center arrow. Similar results have been observed in bilingual children. For instance, Martin-Rhee and Bialystok (2008) tested 4- and 5-year-old bilingual and monolingual children on a Simon task. In this task, participants see a stimulus (e.g. a blue or brown square that changes positions on the screen) and have to respond to the color of a stimulus while ignoring its location. Bilingual children outperformed their monolingual peers on this task, a finding that has been replicated in other studies (Carlson & Meltzoff, 2008; Esposito, Baker-Ward, & Mueller, 2013). For instance, in a recent study with older bilingual children (5 to 9 year-olds), increased proficiency in a second language was associated with better inhibitory control (Tse & Altarriba, 2014).

Does trilingualism lead to even better inhibitory control than bilingualism? One might expect even larger gains in trilinguals because, during production and comprehension, trilinguals would have additional competitor words from *two* non-target languages, thereby requiring more inhibitory control. However, across three studies with younger adults and children, there is no supportive evidence for additional inhibitory control gains in trilinguals.

In one such study, inhibitory function was assessed in 8- to 11-year-old trilingual, bilingual, and monolingual children using the flanker task described above (Poarch & Bialystok, 2015). Trilinguals and bilinguals outperformed monolinguals on the flanker task, but there were no differences between trilinguals and bilinguals, suggesting no additional gains in trilinguals. In a study with younger children (5- to 8-year-old children), the same results were observed. Trilinguals, bilinguals, and monolinguals were assessed on two executive control tasks—the Simon task and a version of the flanker arrows task (Poarch & van Hell, 2012). As was seen with older children, both trilinguals and bilinguals exhibited better performance than monolinguals, but trilinguals did not outperform bilinguals.

The lack of further gains in trilinguals was replicated in a recent study with younger adults (Vega-Mendoza, West, Sorace, & Bak, 2015). In this study, trilingual, bilingual, and monolingual younger adults completed attention tasks that assessed inhibition (for example, in one task, they listened to tones and were asked to count the number of low-pitch tones while ignoring high-pitch tones). Trilinguals and bilinguals outperformed monolinguals, but again trilinguals and bilinguals did not differ from each other.

Why did trilinguals not outperform bilinguals in these studies? We suggest three possibilities. One possibility is that trilingualism did not increase inhibitory demands beyond the demands of bilingualism (which, in turn, did not impel the supply to increase). It could be that, while trilinguals in theory have more competitor words to inhibit than bilinguals, in practice there may be limits to spreading activation in the language system, with an upper bound on how many words become activated and require inhibition; this number could already be reached by bilingualism. It could also be that the increase in demands from monolingualism to bilingualism is less a matter of quantity (a larger number of competitor words to inhibit) and more a matter of quality (shifting to a system where information from a non-target language needs to be inhibited). On this view, trilingualism would not impose higher demands because it would be more of the same process of inhibiting information from a non-target language. Language proficiency may also influence the level of demands. High enough proficiency may need to be developed for the third language to create significant activation (requiring inhibition), and sufficient language proficiency may have not yet developed in the trilinguals that were tested in these studies. This scenario, in which trilingualism does not increase inhibitory demands and, consequently, does increase inhibitory abilities, is depicted in Figure 2.

A second possibility is that trilingualism did, in fact, increase the demands, but that for many of the bilinguals the inhibitory supply was already near their ceiling level and could not advance any further. This scenario, which is illustrated in Figure 3, is especially likely with younger adults, who were at their peak level and may have been less capable of additional gains. Consistent with this explanation, previous research suggests that the bilingual advantage in younger adults is not increased when bilinguals acquire other experiences that improve executive functions, such as video game and music experiences (Bialystok, 2006; Schroeder et al., in press).

A third possibility, depicted in Figure 4, is that trilingualism increased inhibitory demands, but by the time bilinguals acquired a third language and became trilingual, the supply was already higher than the trilingual demands, on account of increases from other inhibitory-demanding activities occurring after bilingual acquisition. With a higher supply than the demands, inhibitory control would not be challenged to develop further.[2]

In short, results from a small set of studies seem to suggest that trilingualism may not lead to additional gains in younger adults' and children's inhibitory control, either because trilingualism does not increase inhibitory demands, or because bilinguals' inhibitory supply is already at ceiling level or above the trilingual demands. While trilingualism does not appear to provide an extra benefit to inhibitory control in children and young adults, it remains possible that trilingualism has

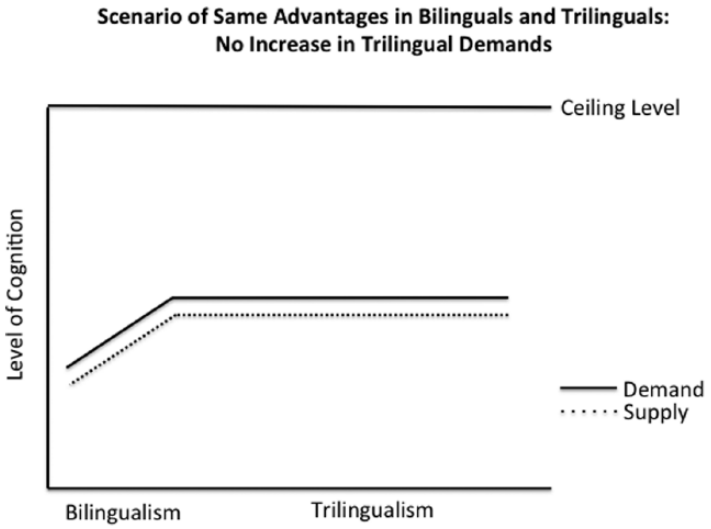

Figure 2. A scenario in which trilinguals would have the same-size advantages as bilinguals. In this situation, the demands of bilingualism and trilingualism are the same. Thus, when transitioning from two languages to three languages, there is no increase in demands and, correspondingly, no increase in supply.

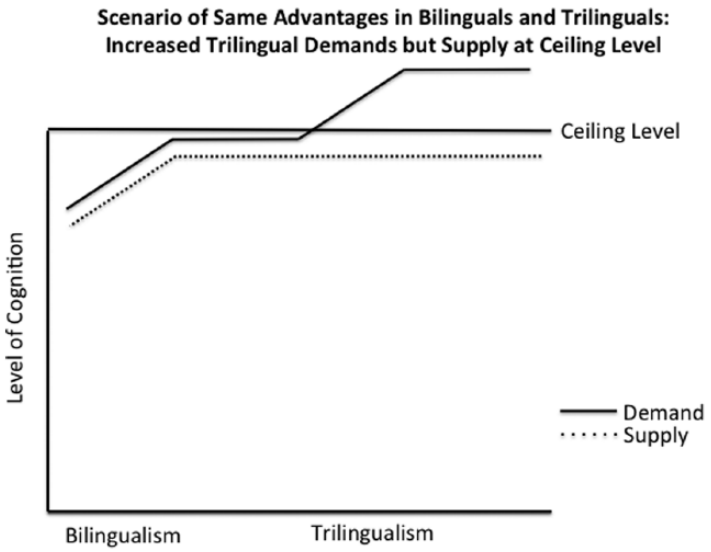

Figure 3. A scenario in which trilinguals would have the same-size advantages as bilinguals. Here there is an increase in demands when transitioning from two languages to three languages. However, a corresponding increase in the supply does not readily occur because of ceiling effects (i.e. neurological constraints limiting further plasticity).

an additional effect in older adults. If the inhibitory demands are not increased through trilingualism, then trilingual older adults will not show additional improvements. Conversely, if the demands are increased, but advantages are not seen in children and younger adults because their inhibitory

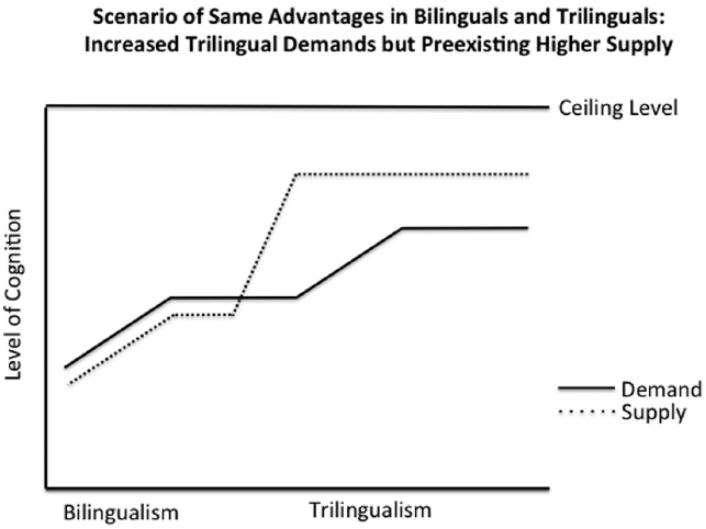

Figure 4. A scenario in which trilinguals would have the same-size advantages as bilinguals. In this case, there is an increase in demands when transitioning from two languages to three languages. However, after learning a second language, and before learning a third language, the person engages in other cognitively demanding activities that increase the supply. When acquisition of the third language begins, the supply is already beyond the level of trilingual demands. Thus, the trilingual demands do not provoke the supply to increase further.

supply is too close to the ceiling or higher than the demands, then trilingual older adults may show further benefits because the decreasing supply from age-related declines would move the supply below the ceiling and the demands; this decline would create a supply–demand mismatch that impels the supply to increase and gives it room to do so. Future work should test trilingual older adults, not only to determine if trilingualism can lead to further gains in inhibitory control, but also to help decide among competing explanations for why these effects are not observed in children and younger adults.

Too much of a good thing: trilingualism decreases the bilingual advantage in infant and toddler memory generalization

In a recent set of studies, bilingual and monolingual children were compared on memory generalization performance (Brito & Barr, 2012; Brito, Grenell, & Barr, 2014). Memory generalization refers to the ability to apply learned information to a new situation. For example, a child may learn that bananas, oranges, and lemons need to be peeled before they are eaten and then apply this knowledge when later encountering a grapefruit. This ability to extend knowledge to new instances is often assessed with the deferred imitation task (Barr, Dowden, & Hayne, 1996; McDonough, Mandler, McKee, & Squire, 1995). In this task, an infant or toddler watches an experimenter manipulate a target object in some way, such as pulling a lever to raise a toy rabbit's ears. Then, after a delay, the infant or toddler has to imitate that behavior on the target object. When something about the target object changes after the delay (such as its color or shape), infants and toddlers sometimes have difficulty imitating the behavior; that is, they have difficulty generalizing the memory to a slightly different object.

Across multiple studies, young bilingual children have been found to outperform their monolingual peers on these types of memory generalization tasks. For example, in a study with 6-month-old bilingual and monolingual infants (Brito & Barr, 2014), bilinguals were able to imitate the behavior (i.e. demonstrate memory generalization) in a difficult task, where the target object changed in two features (color and shape), and in an easy task, where the target object changed in only one feature (color), while monolinguals were only able to imitate in the easy task. In another study, with older participants (18-month-olds) performing a more difficult generalization task, bilinguals demonstrated successful deferred imitation performance, whereas monolinguals did not (Brito & Barr, 2012).

The earlier development of memory generalization in bilinguals has been confirmed by additional studies (see also Brito, Grenell, & Barr, 2014; Brito, Sebastián-Gallés, & Barr, 2015; Singh et al., 2015), but the reasons for this bilingual advantage remain unclear. One explanation is that bilinguals have become better at remembering information in the face of a change in context from encoding to retrieval. While both monolingual and bilingual children often have to retrieve memories despite a context shift (due to spatial, temporal, and other changes from encoding to retrieval), the degree of context shift may sometimes be larger for bilinguals, who may also have a change in linguistic context (Marian & Fausey, 2006; Marian & Neisser, 2000). This larger context shift would increase the demands for bilinguals, which may result in memory-related supply increases that enable bilinguals to better recall information in spite of a context change. Recalling information in spite of a context change is necessary for successfully applying learned information to new contexts (in other words, for displaying memory generalization).

Another explanation relates to the fact that when bilinguals form categories of similar items, they have to do so despite additional surface-level differences (Holowka, Brosseau-Lapre, & Petitto, 2002; Peña, Bedore, Zlatic-Giunta, 2002). For example, an English-speaking monolingual has to notice the similarities among several different dogs that are all called "dog" in order to form the dog category, whereas an English-Spanish bilingual has to notice the similarities among several different dogs that are referred to by either "dog" or "perro" in order to form the dog category. Because the linguistic labels create an additional difference, the ability to form categories among similar items is likely to be more difficult for bilinguals, which could lead to supply increases related to categorization skills. As a result, in the deferred imitation task, the bilingual child may be able to place the new target object in the same category as the old target object despite surface-level differences; this would enable the bilingual child to treat the two objects similarly, which is necessary for successful performance on the memory generalization tasks.

Further explanations include bilinguals having a general memory advantage due to the need to encode, store, and retrieve more linguistic information than bilinguals (Singh et al., 2015), as well as executive functioning advantages stemming from the need to manage two languages instead of one. Executive functioning enhancements may enable bilinguals to focus on the important feature of the target object (i.e. the component that is acted on in the modeling demonstration and remains constant throughout the task) and ignore the less relevant features (e.g. color and form, which change in the task).

Under all of these views, trilingual infants and toddlers potentially face even higher demands than do their bilingual peers. For instance, trilinguals may face increased executive demands from managing additional languages, and increased memory demands from encoding, storing, and retrieving more linguistic information. Also, the challenges of retrieving a memory in a different linguistic context may be increased in trilinguals relative to bilinguals. For example, consider a situation in which a child is attempting to remember that a banana needs to be peeled before it is eaten. A bilingual retrieving this memory in a Language A context might have been exposed to this event three times previously in the Language A context and three times previously in the Language

B context. For a trilingual, they might have been exposed to the event two times in the Language A context, two times in the Language B context, and two times in the Language C context. Given the decreased number of times trilinguals have been exposed to the event in the correct language context (two times for trilinguals versus three times bilinguals), trilinguals may have even weaker contextual retrieval cues than bilinguals, making recall more difficult.

The larger demands faced by trilinguals could, in theory, increase memory generalization abilities to an even greater extent. However, this does not appear to be the case, as two studies have found that not only does trilingualism fail to yield further benefits beyond bilingualism, trilingualism also fails to yield to the benefits of bilingualism. For example, in a recent study, 18-month-old monolinguals, bilinguals, and trilinguals were compared on a memory generalization task, in which actions, like removing the mitten on a toy animal, had to be generalized 30-minutes later to a different toy animal (Brito, Sebastián-Gallés et al., 2015). Bilinguals successfully generalized, but trilinguals and monolinguals did not. A similar finding was observed in a study comparing 24-month-old monolinguals, bilinguals, and trilinguals (Brito, Grenell et al., 2014). Memory generalization occurring 24 hours after encoding was achieved by the bilingual toddlers, but not by the trilingual or monolingual toddlers. Thus, some initial research suggests that while bilinguals may demonstrate an advantage over monolinguals, trilinguals may not; however, more work is needed to confirm this trend given that it is based on only a small set of studies from a single laboratory. (It is important to note that, in these studies, trilinguals also did not demonstrate a deficit relative to monolinguals.)

Why might trilinguals fail to even show the benefits of bilingualism? Because all the infant and toddler trilinguals in these studies were simultaneous monolingual-bilingual-trilinguals (with all three languages acquired from birth), their cognitive demands would be extremely steep, particularly given the low cognitive supply in infants and toddlers. With too high a level of difficulty, trilinguals may not only fail to show a further gain, they may fail to even show the advantages observed in bilinguals, whose difficulty level is lower and therefore more manageable. Because excessively high demands can lead participants to give up on the task or use alternative mechanisms (Lövdén et al., 2010), trilinguals may not show enhancements, a scenario that is depicted in Figure 5. However, it is possible that trilinguals who use their third language very little (and therefore are more similar to bilinguals) would have the optimal level of difficulty and therefore would exhibit some gains. In a follow-up analysis, Brito, Grenell, and Barr (2014) observed a trend toward trilinguals with less third language experience (less than 10% of the time) outperforming trilinguals with more third language experience (33% of the time). It is also possible that trilinguals who are older than infants and toddlers and/or learned their second and third language sequentially could show an advantage that is greater than bilinguals, because a higher supply (in older trilinguals) and gradually increasing demands (in sequential bilingual-trilinguals) would make the demands more manageable. Future research should assess older and sequential bilingual-trilinguals to see if they perform above, below, or the same as bilinguals.

Conclusions

In this review, we compared trilingual cognition to bilingual cognition. In the first section, we stated some of the reasons why it is important to consider trilingual cognition in addition to bilingual cognition, including theoretical implications for developing accurate models of cognition and for understanding cognitive plasticity, as well as practical implications for designing effective educational and clinical programs. In the next section, we laid out a supply–demand cognitive plasticity framework to account for why trilinguals may or may not demonstrate stronger cognitive advantages than bilinguals. Subsequently, we reviewed evidence suggesting that trilingual

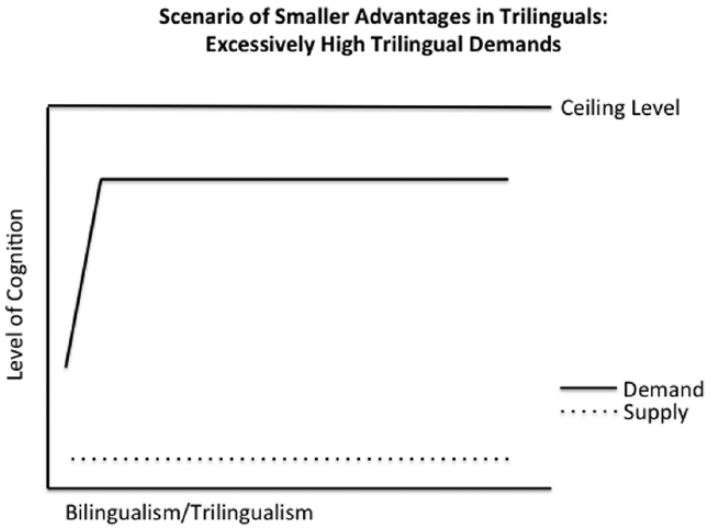

Figure 5. A scenario in which trilinguals would not show any cognitive enhancement (in contrast to bilinguals, who do show a cognitive enhancement). In this situation, a person learns the second and third language simultaneously; there is, therefore, a suddenly large increase in the demands (rather than a gradual increase in the case of sequential second-to-third language acquisition). Additionally, the supply is low (e.g. in infants). Because the demands are excessively above the supply, the task is too difficult and no increase in the supply occurs.

older adults may show larger gains than bilingual older adults in cognitive reserve. According to the supply–demand framework, trilingual older adults may have more cognitive reserve than bilingual older adults because trilingualism increases the demands placed on memory and executive processes, leading to a corresponding supply increase. Next, we reviewed research indicating that trilingual children and younger adults may not outperform their bilingual peers in inhibitory control. According to the proposed supply–demand framework, trilinguals do not outperform bilinguals either because their inhibitory demands are not increased or because their inhibitory supply is too close to the ceiling or above the demands, all of which prevent trilinguals from increasing their supply above that of bilinguals. Lastly, we discussed preliminary evidence suggesting that trilingual infants and toddlers actually perform worse than bilinguals in memory generalization. Trilingual infants and toddlers may face cognitive demands that are too high relative to their small supply, preventing trilinguals from increasing their supply even to the level of bilinguals.

The supply–demand framework laid out here may be useful when conducting future work on bi- and trilingual cognition, including applied research in education and cognitive training. For example, it has been suggested that taking foreign language classes may be an effective form of cognitive therapy for older adults (Antoniou, Gunasekera, & Wong, 2013). According to the supply–demand framework, the effectiveness of these programs will depend on whether language learning lessons are designed to place demands that are continuously optimally above older adults' cognitive supply. The supply–demand framework may also be helpful when examining trilinguals' performance on other aspects of cognition that are enhanced in bilinguals. While trilingualism research has been done on cognitive reserve, inhibitory control, and memory generalization, very little work has been done on lip-reading, word learning, creativity, and sound encoding, all of which are thought to be improved in bilinguals (Kaushanskaya & Marian, 2009; Kharkhurin, 2009;

Krizman, Marian, Shook, Skoe, & Kraus, 2012; Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012). This review shows that any generalizations about trilingual–bilingual differences (for example, an assumption that trilinguals will outperform bilinguals in all tasks) are misguided, given the complex patterns illustrated here; thus, additional empirical research is needed to compare trilinguals, bilinguals, and monolinguals on these abilities and to unravel the complex nature of bi- and multilingual cognition.

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Notes

1. While observed frequently, bilingual enhancements are not always found (Paap & Greenberg, 2013; Paap & Liu, 2014). Nevertheless, in meta-analyses, which take into account both successful replications and replication failures, a significant bilingual advantage is observed, suggesting that successful replications outweigh replication failures (Adesope, Lavin, Thompson, & Ungerleider, 2010; Donnelly, Brooks, & Homer, 2015). Though one might argue that replication failures are underrepresented in meta-analyses, due to publication biases against null results (de Bruin, Treccani, & Della Sala, 2015), many replication failures may not be published due to methodological flaws (including small sample sizes, important differences between monolinguals and bilinguals in variables other than language experience, and inappropriate experimental tasks) rather than biases against null results. Furthermore, when a study fails to replicate the bilingual advantage, it is often in younger adults, who are at the peak of their cognitive abilities and near-perfect on many computer-based experimental tasks, leaving minimal room to observe group differences (but see Costa, Hernández, & Sebastián-Gallés, 2008; Vega-Mendoza, West, Sorace, & Bak, 2015, among others, for bilingual advantages in younger adults, and see Bialystok, in press, for a more detailed discussion). In children and older adults, who are not at the peak of their cognitive abilities, there is strong evidence for bilingual advantages (Bialystok, Craik, Klein, & Viswanathan, 2004; Carlson & Meltzoff, 2008; Kovács & Mehler, 2009).
2. In this scenario, bilinguals and trilinguals would still have advantages over monolinguals, even though all three groups would be equally likely to engage in other executive-demanding activities. Bilinguals and trilinguals would have more repetitions of supply–demand mismatches than monolinguals (because they encounter mismatches during non-linguistic activities *and during language processing*), which, in turn, would pull the bilinguals' and trilinguals' supply closer to the demands than monolinguals'. Moreover, bilingualism and trilingualism may increase the plasticity of executive processes, enabling them to be more responsive to other executive-demanding activities.

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