Doctoral Dissertation

The Relationship between Executive control and Language:
Evidence from Bilinguals and L2 learners in different Immersion Environments

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April 2016

Editor: Universidad de Granada. Tesis Doctorales
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ISBN: 978-84-1306-122-1
URI: http://hdl.handle.net/10481/54941

Acknowledgments

Quiero darle las gracias a mi directora de tesis, Teresa, por apoyarme y confiar en mí siempre, pero más que nada por abrirme la puerta a Granada e invitarme, y así, darme la oportunidad de pasar aquí estos años que para mí han sido verdaderamente un regalo. Gracias también a mi grupo de investigación por vuestra compañíá, vuestro apoyo, las risas, y muchos momentos compartidos. A Carmen, no puedo agradecerte más tu ayuda y tu paciencia escuchándome, y a Ana, por todo el esfuerzo en la contribución a mi tesis, lo que me has enseñado y lo que aprendimos juntas. Gracias, Lina y Alicia, por haber sido mi familia lejos de mi familia en estos años.

A thank you goes to Judy and her group at the Center of Language Science in Penn State for welcoming me into their lab and doing everything in their power so that I could keep collecting data in the middle of a move. I am especially thankful to Eleonora and Nick, Because of you, I felt at home in State College, and I appreciate it so much. Thanks to so many friends over the years and along the way. Thank you, Laura and Noelle, for making the last year so much better and more fun, I am so glad I met you. Thank you, Peter, for being by my side always. Among the many other things that you are to me, you are a scientist, and I have learned so much from you and your inquisitive mind.

Von Herzen danke ich meiner Familie, meinen Eltern und meinen beiden Brüdern Benjamin und Emanuel. Eure unbedingte Unterstützung bedeutet mir so viel.

Euch allen, to all of you, a todos vosotros, muchas gracias de corazón.

Chapter I

Introduction and aims

Abundant evidence suggests that the relationship between language and other cognitive functions is a dynamic, interactive, and reciprocal one (e.g. Iverson, 2010, Majid, Bowerman, Kita, Haun & Levinson, 2004, Marchman & Fernald, 2008, Seniów, Litwin, & Lésniak, 2009). Marking a shift from earlier, modular views, neurobiological models of language processing are now being reformulated to include domain-general, nonlinguistic executive control[1] functions (e.g., Cahana-Amitay & Albert, 2014), and ontogenetically, linguistic and executive control abilities develop in close interdependence (for a review, Müller, Jacques, Brocki, & Zelazo, 2009). Crucial evidence shaping our current understanding of the functional principles of language and the interface between linguistic and general cognitive control comes from the study of bilingualism[2]. Where, within a monolingual system, speakers need to coordinate numerous sequential and parallel processes to control linguistic input and output, in bilinguals, who are equipped with at least two sets of linguistic rules and labels, control demands are multiplied. How do speakers of two or more languages manage to meet these demands? Two important findings have emerged from the study of bilingualism in the last two decades, inspiring immensely prolific research and leading to the formulation of detailed theoretical frameworks of how bilinguals negotiate the attentional demands of multiple languages (e.g., Green, 1998, Green & Abutalebi, 2013, Stocco, Yamasaki, Natalenko, & Prat, 2014).

One is the observation that when bilingual minds process language, the non-target language is always activated, evidenced by subtle influences on the target language even in purely monolinguals settings (Van Hell & Dijkstra, 2002, Thierry & Wu, 2007). The second one is the finding that bilinguals often outperform monolinguals on behavioral tasks that require executive control (e.g., Adesope, Lavin, Thompson & Ungerleider, 2010, Bialystok,

[1] The terms “executive control” and “cognitive control” will be used interchangeably to refer to the same concept.

[2] Many people use more than two languages in their daily lives. I will use the generic term “bilingualism” to refer to the knowledge and use of any number of languages larger than one.

2001, Bialystok, 2009). How are these two findings related? The continuous parallel activation of target and non-target language evident in bilinguals who have reached a certain level of proficiency gives rise to cross-linguistic interference (Rodriguez-Fornells, Heinze, Nösselt & Münte, 2002, Rodriguez-Fornells, Van der Lugt, Rotte, Britti, Heinze & Münte, 2005). To illustrate, Green (1998) likens the translation of a written word from one language to the other to a Stroop task, in that the translator must *"avoid naming the printed word and, instead, produce a translation equivalent"* (pp. 67, 24-25). In light of constant co-activation of the non-target language, it seems that there is *always* interference to be overcome in a bilingual's mind, and there is now evidence that cross-language interference arises across levels of linguistic representation, such as at the phonological, the lexical, and the syntactic level (see Kroll, Dussias, Bogulski, & Kroff, 2012). If life is a constant Stroop task for bilinguals, it should come as no surprise if they performed really well on this kind of task[3]. On the other hand, it has been found that monolinguals perform better than bilinguals in the verbal domain, showing more accurate or efficient language processing (e.g., Bialystok, 2009). This is true even for a bilingual's native and dominant language. Similar to between-group-differences for executive control, the latter finding has been related to parallel language activation in bilinguals. In the process of retrieving and producing words, bilinguals experience competitor interference from the active irrelevant language which could explain their less efficient performance. From this perspective, bilingual executive advantages and linguistic costs are two sides of the same coin. Together, they point to a link between executive control and language processing. Central to this work is the concept that control demands associated with bilingual language processing are, to a substantial degree, met in the form of domain-general cognitive resources that are both capacity-limited, and subject to individual differences. Underlying this notion is a compound hypothesis, where none of the elements are beyond dispute, and their connection

[3] As it turns out, there are other paradigms better suited than the Stroop task to study the bilingual executive advantage, however, it makes for a good illustration of the underlying principle.

remains largely speculative. The bilingual executive advantage hypothesis in particular has recently come under fundamental criticism (De Bruin, Treccani, & Della Sala, 2015, Paap & Greenberg, 2013). We will look at the presented hypothesis and its implications from different angles, with special interest in the boundary conditions that limit and give rise to the manifestations of the interaction between linguistic experience and domain-general executive control. The remainder of the introduction will provide a summary of the recent literature on executive control and linguistic abilities in bilinguals, including a discussion of some of the factors that may condition the emergence of monolingual vs. bilingual differences in cognitive task performance. An outline of the role of executive control in language processing follows. The experimental series following the introduction contributes evidence regarding each of these issues.

1. How does bilingualism modulate cognition?

Considering the close interdependency between linguistic and nonlinguistic cognitive development (see, e.g., Gooch, Thompson, Nash, Snowling, & Hulme, 2016, Schneider, Schumann-Hengsteler, & Sodian, 2014) it is conceivable that bilingualism may alter the developmental course of cognitive functions, but in which ways do bilingual and monolingual minds differ from each other? As mentioned above, a frequently reported pattern is that of a cost or delay in the linguistic domain, coupled with enhanced executive control in bilinguals compared to monolinguals (Bialystok, 2001), both of which have been traced back to the same source, namely, parallel language activation and resulting cross-language interference in bilingual language processing. In the following two sections we will summarize the relevant empirical evidence.

1.1 Bilingualism as a cognitive training: Enhanced executive function in bilinguals

A bilingual executive advantage was first postulated by Bialystok (1999), who found that, compared to age-matched monolinguals, young bilingual children showed enhanced selective attention on various linguistic and non-linguistic distractor tasks. She proposed that bilingualism leads to precocious development of executive control. Since then, evidence for enhanced executive control has been extended from bilingual children (e.g., Carlson & Meltzoff, 2008, Nicolay & Poncelet, 2015, for reviews, Adesope, Lavin, Thompson, & Ungerleider, 2010, Bialystok, 2015), to young adults (e.g., Bak, Vega-Mendoza, & Sorace, 2015, Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011, Yang,Yang, & Lust, 2011), as well as middle-aged and older adults (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004). This intriguing finding has been interpreted by many to reflect the fact that language processing is associated with increased attentional demands for bilinguals compared to monolinguals, and that over time, bilinguals not only show adaptation to these increased attentional demands, but their adapted executive skills also transfer from language control to non-linguistic domains. From this perspective, using multiple languages regularly serves as a type of incidental cognitive training of the executive control system, and as such, constitutes an example of experience-based neurocognitive plasticity. Consistent with this interpretation, neuro-structural differences such as greater grey matter (GM) density or white matter (WM) integrity in bilinguals compared to monolinguals have been observed in brain areas associated with language and executive control (e.g., Abutalebi, Canini, Della Rosa, Green, & Weekes, 2015, Luk, Bialystok, Craik, & Grady, 2011, Mechelli et al., 2004, Olsen et al., 2015, Richardson & Price, 2009, for a review, see Li, Legault & Litcofsky, 2014).

While most evidence regarding the cognitive consequences of bilingualism in this context comes from cross-sectional research, more recently, researchers have started to investigate the effects of emerging bilingualism and second language acquisition on the executive control system longitudinally. This is especially important given the inherent methodological limitations of cross-sectional studies. Recent studies have observed longitudinally emerging executive advantages in both children who were in the process of becoming bilingual through L2 immersion at school (Nicolay & Poncelet, 2015) and in adults starting to actively engage in bimodal bilingualism (Macnamara & Conway, 2014). Yet another study investigating the initial stages of L2 acquisition found that after only a few months of L2 training, second language learners showed increased P3 effects, reflecting enhanced interference resolution, on a go-no go task. Furthermore, increase in P3b amplitude was correlated with the level of L2 proficiency achieved on the individual level (Sullivan, Janus, Moreno, Astheimer, & Bialystok, 2015). Studies like these reveal a temporal continuity in the emergence of the cognitive-executive consequences of bilingualism. In addition, longitudinal studies yield the possibility to explore *how* adaptive effects might occur over time, and can therefore be particularly informative in regards to the mediating mechanisms. A particularly creative approach to studying adaptation effects on-line was adopted by Wu and Thierry (2013). In their study, bilingual participants were presented with an interference task that was divided into blocks where experimental trials were interspersed with words from either one language, or both languages. The authors found reduced interference for the mixed relative to the single language blocks. A possible explanation of this finding is that the detection of a mixed language context prompts an upregulation of cognitive control in bilingual participants. Research in the field of cognitive plasticity shows that constant optimization of available resources eventually leads to the extension of resource limitations (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010). From this perspective, these data align with the understanding of bilingualism as a challenging cognitive activity that, if practiced regularly, leads to relatively enduring, stable cognitive adaptation effects.

Although the body of evidence suggests that bilingualism may in fact convey adaptive effects to the executive control system, data do not always converge in regards to what exactly this adaptation consists in. Executive control is a multifaceted construct, exerted by an array of cognitive processes or mechanisms working in concert to enable goal-directed and non-routine behavior. Thus, the effects of bilingualism may be selective to specific executive mechanisms, or they may lie in a modulation of the interaction or coordination of different mechanisms or control states (see, for example, Morales, Gómez-Ariza, & Bajo, 2013). Different proposals have been made regarding the locus of the putative effect within the executive control system. In part, such differences reflect the fact that researchers have sometimes interpreted their findings on the basis of different taxonomies of executive functions.

Inhibitory accounts

A popular model of executive control postulates inhibition (controlled suppression of prepotent responses or interfering representations), set shifting (switching attentional focus between different task sets), and updating (monitoring and refreshing the content of working memory) as empirically and conceptually separable, core executive functions (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Especially the earlier studies in this field, but also many recent accounts have focused on inhibitory control (e.g., Bialystok, 2001, Fernandez, Tartar, Padron, & Acosta, 2013, Moreno, Wodniecka, Tays, Alain, & Bialystok, 2014, Poarch & van Hell, 2012, Wimmer & Marx, 2014), often citing the three-component model of executive function (Miyake et al., 2000). The understanding that bilingualism specifically affects inhibition results from evidence that bilinguals show reduced interference effects on conflict trials in paradigms such as the Stroop (e.g., Blumenfeld & Marian, 2011, Martin-Rhee & Bialystok, 2008, Tse & Altarriba, 2012, Zied et al., 2004), flanker (e.g., Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009, Costa, Hernández, & Sebastián-Gallés, 2008, Poarch & van Hell, 2012, Tao et al., 2011) and Simon task (e.g., Bialystok et al., 2004, Bialystok et al., 2005, Poarch & van Hell, 2012), compared to monolingual participants. The size of interference costs (i.e., the difference in performance measures for compatible and incompatible trials of an interference task) can be used as a measure of individual differences in inhibitory abilities, with smaller interference effects reflecting increased inhibitory control (e.g., Friedman & Miyake, 2004, Miyake et al., 2000). Enhanced and persistent inhibition in bilinguals has been observed even in cases where it is detrimental to task performance (Prior, 2012, see also Colzato et al., 2008). In line with these findings, models of bilingual language control propose that cross-linguistic interference in bilinguals' lexicalization is resolved by means of inhibitory control (Dijkstra & Van Heuven, 2002, Green, 1998), and there is empirical evidence to support this assumption (e.g., Blumenfeld & Marian, 2011, Martín, Macizo, & Bajo, 2010, Misra, Guo, Bobb, & Kroll, 2012).

On the other hand, bilingual advantages have also been observed for working memory (e.g., Blom, Küntay, Messer, Verhagen, & Leseman, 2014, Bogulski, Rakoczy, Goodman, & Bialystok, 2015, Morales, Calvo, & Bialystok, 2013) and task switching paradigms (e.g., Prior & MacWhinney, 2010, Prior & Gollan, 2011, Vega-Mendoza , Bak, & Sorace, 2015, Wiseheart, Viswanathan, & Bialystok, 2016), sometimes in absence of between-group differences in inhibitory control (e.g., Bogulski et al., 2015, Nicolay & Poncelet, 2013). Furthermore, bilingual performance advantages on interference tasks are often not limited to conflict trials. In fact, it appears that a more consistent finding is a global advantage on interference tasks, across conflict and non-conflict trials (e.g., Costa et al., 2009, for review, Hilchey & Klein, 2011).

Proactive cognitive control

A model that explains the functional principles of executive control from a broader level of analysis is the Dual Mechanism Framework (Braver, 2012). This framework describes two modes of cognitive control - Proactive vs. Reactive Control - that guide executive attention during goal-directed performance. As individuals engage in a task, they may face distraction from environmental stimuli or internally processed information which divert the attentional focus from the task set. Executive control may be exerted proactively, biasing attention and perception towards task-relevant information and thereby decreasing the probability of interference so that the attentional focus can be maintained (Proactive Control). Thus, to be effective, Proactive Control is exercised pre-emptively, in absence of interference or attentional conflict. Reactive Control, on the other hand, is triggered momentarily when a distraction has occurred in order to return the attentional focus from the source of interference to the task set.

Several alternative proposals have focused on mechanisms of proactive control to explain the differential response patterns observed for monolinguals and bilinguals on executive tasks (e.g. Colzato et al., 2008, Costa et al., 2009, Hernández, Costa, & Humphreys, 2012). Accordingly, rather than enhancing the strength or efficiency of inhibition that is triggered by interfering information on a moment-to-moment basis, bilinguals’ experience with managing the attentional demands of two languages might increase their ability to maintain the attentional focus on a current task set, reducing the susceptibility to interference before it occurs (Hilchey & Klein, 2011). Enhanced proactive control might be implemented through increased conflict monitoring (Costa et al., 2008), by virtue of a stronger, more stable goal representation or more effective implementation of goal-supporting processes (Colzato et al., 2008). More specifically, bilinguals might be able to build a more efficient task representation by compartmentalizing goal-relevant and irrelevant information in WM, as evidenced by the fact that bilinguals experience less interference from irrelevant information retained in WM during task performance (Hernández et al., 2012). Although bilinguals cannot “switch off” the influence of a non-target language entirely (see Kroll et al., 2012), they are able to use contextual cues such as the sentence context to reduce parallel activation and cross-linguistic interference proactively (e.g., Schwarz & Kroll, 2006, FitzPatrick & Indefrey, 2014). Accordingly, bilinguals might develop a tendency to exercise cognitive control in a more proactive fashion, or they might achieve a higher level of efficiency when operating in a proactive control mode. In line with hypotheses centering on proactive control, there is evidence that a short-term training in bilingual language control results in a behavioral shift towards more proactive control (Zhang, Kang, Wu, Ma, & Guo, 2015), and bilingual advantages seem to be more likely to emerge when the demands for anticipatory monitoring are high, that is, when participants are likely to engage a proactive control mode as opposed to a reactive control mode (Costa et al., 2009).

Contrary to single-process accounts, an adaptation of proactive control requires the coordination of various executive resources and processes. Inhibition in the context of bilingual language control and non-linguistic executive control in bilinguals has typically been interpreted (at least implicitly) in terms of a reactive control mechanism that targets interfering information once it arises (see, for example, Green, 1998, Misra et al., 2012, Prior, 2012, Van Assche, Duyck, & Gollan, 2013). However, inhibition can be implemented proactively (Aron, 2010), and instances of increased inhibition in bilinguals can also be integrated into a proactive account, for example, in terms of a byproduct of a proactive control state, wherein processing is biased towards target representations, at the expense of non-target representations (Colzato et al., 2008). On the other hand, proposals that center on proactive control can less readily account for situations where bilinguals specifically show increased conflict resolution or inhibition but similar monitoring performance compared to monolinguals (e.g., Prior, 2012, Poarch & van Hell, 2012).

Integrative accounts: Coordination of multiple control mechanisms

A third group of proposals holds that bilinguals' practice in multiple language management does not modulate individual mechanisms or specific control states, but rather, their coordination and dynamic interaction (Morales et al., 2013, Morales, Yudes, Gómez-Ariza, & Bajo, 2015, see also Bialystok, 2011, Bialystok, Craik, & Ruocco, 2006). Individual executive components always work in concert (Miyake et al., 2000, Miyake & Friedman, 2012), and although participants may operate primarily in a proactive or reactive control state depending on individual and task-level differences, proactive and reactive control interact (Braver, 2012, Burgess & Braver, 2010). For example, when performing a cognitive task, a participant may reduce the incidence of interference by exerting proactive control (for example, by maintaining the task representation steadily in WM and monitoring the environment for upcoming demands), but even so, non-target representations may occasionally succeed in distracting attention, in which case reactive control of interference becomes necessary. In addition, when task demands change, anticipatory cues that prompt a certain response might be misleading. In these cases, performance depends on participants' ability to readjust different control modes, rapidly engaging and disengaging reactive control mechanisms. Using a version of the AX-Continuous Performance Task (AX-CPT) that encourages reliance on proactive control (Braver, 2012), Morales and colleagues (2013, 2015) showed that compared to a monolingual control group, young adult bilinguals were able to more readily engage reactive control processes when a proactive control strategy unexpectedly triggered an erroneous response. In other words, bilinguals did not simply show enhanced reactive or proactive control, but excelled, specifically, in situations that required a reactive readjustment of a proactive control mode (Morales et al., 2013, 2015).

Of note, the paradigm used by Morales and colleagues (2013, 2015) does not require participants to shift their attention between different task representations. However, situations that require changing between task sets would equally benefit from a finely-tuned adjustment of reactive and proactive control states. Real-life language tasks and target language requirements may change rapidly in interactive bilingual environments. In these situations, reactive control is more than a “repair” program that is triggered when proactive control has failed: because it is triggered on a moment-to-moment basis and does not privilege a specific task set, reactive control is resource-conservative and allows greater flexibility to react to non-target representations. Essentially, the dynamic interplay between control modes or mechanisms ensures efficient task-disengagement when the net benefit is greater than the net cost. Thus, an improved coordination of different control states could also account for bilingual advantages in task switching (Prior & Gollan, 2011, Prior & MacWhinney, 2010, Vega-Mendoza et al., 2015).

In sum, a growing body of data suggests that bilinguals’ dual language experience conveys adaptive effects to the executive control system, and different theoretical proposals have been put forth in regards to the locus and the mechanism mediating this bilingual advantage. Alternative accounts center on inhibition or proactive control mechanisms such as anticipatory monitoring or goal maintenance, whereas more holistic accounts aim to reconcile these approaches by localizing the effect at the level of regulation or coordination of different mechanisms. A problem that all these proposals share, however, is the fact that the effects of bilingualism are at times inconsistent. Critics argue that data from different bilingual populations should converge on a characteristic pattern. However, between-group-differences are not always replicable (see, for example, Hernández, Martin, Barceló, & Costa, 2013, Morton & Harper, 2007, Namazi & Thorardottir, 2011). This apparent inconsistency has recently led to some fundamental criticism of the bilingual executive advantage hypothesis (e.g., Antón et al., 2014, Duñabeitia et al., 2015, Paap & Greenberg, 2013). With much research on the cognitive consequences of bilingualism having been conducted cross-sectionally, some have argued that bilingual-vs.-monolingual performance differences may in fact result from unnoticed covariance with sociodemographic variables such as socio-economic status (SES) and bicultural experience rather than language experiences per se (e.g., Morton & Harper, 2007, Paap & Greenberg, 2013). To the extent that these factors can be identified, some of them can be ruled out. For example, empirical data attest that the effect of bilingualism on executive control is independent from (Calvo & Bialystok, 2014, Thomas-Sunesson, Hakuta, & Bialystok, in press), and not limited by SES (Engel de Abreu, Cruz-Santos, Tourinho, Martin & Bialystok, 2012). In addition, more recently emerging longitudinal research (e.g., Macnamara & Conway, 2014, Nicolay & Poncelet, 2015) allows greater experimental control over external variables and thus far seems to support the assumption that bilingualism is associated with increased cognitive control. However, it is undeniable that issues of self-selection might weigh into who will develop full functional bilingualism in the first place. A particularly interesting observation in this context was made in a recent study on the genetic underpinnings of cognitive control. In a group of 182 college students, a substantially higher proportion of bilinguals were carriers of a gene variation associated with increased cognitive flexibility than in the monolingual reference group (Hernandez, Greene, Vaughn, Francis, & Grigorenko, 2015). Much research remains to be done in order to understand how bilingualism interacts with the multitude of social and individual factors that modulate and shape, limit and foster the development of cognitive systems.

However, putting these issues aside, an interesting question is whether data from different bilingual populations, sampled by means of a set of conceptually overlapping tasks should really necessarily converge in order to support the notion that dual language experiences can affect the efficiency of the executive control system. Recent literature emphasizes the diversity of bilingual environments (see, for example, Baum & Titone, 2014, Green & Abutalebi, 2013, Luk & Bialystok, 2013) and the challenge imposed by measurement constraints on executive tasks (e.g., Kroll & Bialystok, 2013), particularly from a wider perspective of bilingual costs and benefits (Bialystok, 2009, Blom et al., 2014).

To illustrate, consider the effects of bilingualism over the life span. As mentioned above, cognitive-executive advantages have been observed for bilinguals across ages. However, bilingual advantages do not always take the same shape in different life stages, simply because the executive system is not the same. For example, Bialystok, Martin and Bialystok (2005) detected a bilingual advantage in inhibitory control for children, middle-aged and older adults, but not for young adults in their early to mid-twenties. This finding can be explained as due to the fact that young adults have reached a peak in their individual levels of executive functioning, and the same tasks do not have the same discriminatory power as they do in samples that reach levels of less-than-optimal performance such as children, old age, or perhaps clinical populations. The ability to exercise executive control emerges and develops over childhood and into adolescence, and the interrelation of executive components and their role in overall cognitive ability may change over time (Senn, Espy, & Kaufmann, 2004). Thus, studies with preverbal infants suggest that bilinguals display premature development of precursors of executive control such as the ability to override a previously learned response (Kovacs & Mehler, 2009) or more efficient habituation to novel stimuli (Singh et al., 2015), using measures that are not functionally discriminative at later developmental stages. Similarly, a bilingual advantage in motor inhibition has only been observed in toddlers aged 3-4, a critical age for this component which is known to develop ontogenetically earlier than other forms of inhibitory control (Bialystok, Barac, Blaye, & Poulin-Dubois, 2010). Conversely, in old age, lifelong bilingualism contributes to cognitive reserve, offsetting the functional effects of normal aging and delaying symptom onset in certain types of dementia (see, e.g., Antoniou, Gunasekera, & Wong, 2013, Mortimer, Alladi, Bak, Russ, Shailaja, & Duggirala, 2014, Schweizer, Ware, Fischer, Craik, & Bialystok, 2012). Age-related performance difficulties on tasks involving, but not directly measuring, executive control increase the visibility of between-group differences that remain unnoticed in younger participants. This way, developmental changes provide a window to study the effects of bilingualism. Upcoming sections 1.3.1 and 1.3.2 will elaborate on the issues of participant- and task-related variability more extensively, but beforehand, we turn to another cognitive domain where differences in development and attainment have consistently been demonstrated, that is, the language domain.

1.2 Cognitive load and limited exposure: Linguistic costs in knowledge and processing

The previous section presented the consequences active bilingualism has for non-linguistic executive processes. However, as one might suspect, bilinguals also differ from monolinguals *precisely* in regards to linguistic processes and abilities. As previously mentioned, data from the linguistic domain show a different picture compared to executive processes (e.g., Bialystok, 2009). Across the literature, data converge on a number of characteristic findings. One area of assessment where patterns for monolinguals and bilinguals consistently diverge is the formal knowledge of language representations, especially vocabulary size. Amounting evidence shows that bilinguals across age groups possess smaller vocabularies than age-matched monolinguals (for review, Bialystok, 2001). Using receptive vocabulary tests, two-large scale studies (N > 1600) found smaller scores for bilinguals compared to monolingual reference groups across all age groups for children aged 3 to 10 (Bialystok, Luk, Peets, & Yang, 2010) and adults aged 17 to 89 (Bialystok & Luk, 2012). This finding has consistently been replicated with smaller samples (e.g., Bialystok, Craik, & Lust, 2008, Bialystok & Feng, 2009, Portocarrero, Burright &

Donovick, 2007). Research has often focused on receptive measures, although bilingual-vs.-monolingual differences have also been found in regards to productive vocabulary (for children, Oller et al., 2007, for young adults, Portocarrero et al., 2007), and early productive vocabulary growth has been found to advance more quickly in monolingual than in bilingual toddlers (Vagh, Pan, & Mancilla-Martinez, 2009). It is important to note that unlike receptive vocabulary tests, productive tests do not provide a pure measure of lexical knowledge. Production tasks additionally require lexical retrieval, meaning that participants have to search and select the most appropriate representation among all entries in their lexicon to produce the item in question. Consistent with vocabulary tests in children, tasks such as the Boston Naming Test have yielded lower accuracy scores in bilingual compared to monolingual reference groups in adulthood and old age (Bialystok, Craik, & Luk, 2008, Kohnert, Hernandez, & Bates, 1998, Gollan, Fennema-Notestine, Montoya, & Jerningan, 2007, Roberts, García, Desrochers, & Hernandez, 2002).

Although the patterns for reception and production are similar, it is important to note there is some evidence for a partial dissociation. Yan and Nicoladis (2009) found the discrepancy between bilingual and monolingual children to be considerably more pronounced for productive than for receptive measures of vocabulary (where in fact, differences were marginal). In the same study, bilingual children stated they did not know a certain item during the production task that they were later able to identify during the receptive portion of the task more frequently than did monolinguals. This pattern points to difficulties with lexical access that go beyond mere lexical knowledge. Consistent with the notion of a specific deficit in lexical access, bilinguals are more likely to experience tip-of-the-tongue retrieval failures (Gollan & Acenas, 2004, Gollan, Montoya, & Bonanni, 2005, Yan & Nicoladis, 2009), and show slower naming latencies even for successfully produced words (e.g., Gollan, Montoya, Cera, & Sandoval, 2008, Gollan, Montoya, Fennema-Notestine, & Morris, 2005, Ivanova & Costa, 2008). Slower lexical access in bilingual participants extends to comprehension tasks (e.g., Ransdell & Fischler, 1987, Rogers, Lister, Febo, Besing, & Abrams, 2006), and in addition, may account for another frequent finding, namely, reduced verbal fluency compared to monolinguals (e.g., Gollan, Montoya and Werner, 2002, Rosselli et al., 2000, Bialystok, Craik, & Luk, 2008a, Portocarrero et al., 2007). Bilinguals' slower processing speed is also evident in the production of noun phrases (Sadat, Martin, Alario, & Costa, 2012) and complex sentences (Runnqvist, Gollan, Costa, & Ferreira, 2013). In addition to a behavioral slow-down, bilinguals engage a more distributed network during naming, indicating increased processing cost (Palomar-García et al., 2015).

Many of these studies compared bilinguals' L2 to monolinguals' L1, which may lead one to ask to what extent the outcomes for both groups are really comparable. However, in most of these cases the L2 had become bilinguals' dominant language, and had also been their language of schooling. In any case, a number of studies have tested both languages of the bilingual sample and have found similar results (i.e., a linguistic advantage in monolinguals) independently of the language of choice. Thus, bilinguals tend to control smaller vocabularies in both languages than monolinguals do in their L1 (e.g., Ben-Zeev, 1977a, Pearson & Fernández, 1994, Umbel, Pearson, Fernández, & Oller, 1992, Yan & Nicoladis, 2009), and the decreased lexical access extends to bilinguals' dominant language whether it is the L2 (Gollan et al., 2002) or the L1 (Ivanova & Costa, 2008). What is more, there is preliminary evidence that a reduction in lexical access, and more generally, in verbal processing speed, can occur in sequential bilinguals who grew up monolingually, as a consequence of L2 acquisition and immersion in adulthood (Linck, Kroll, & Sunderman, 2009).

To fully understand how development and processing of language in bilinguals differ from monolinguals and identify the source of these differences, it is important to consider the overall pattern for different areas of linguistic competence. In young children, vocabulary size is often referred to as a central indicator of overall linguistic (or even general cognitive) development (e.g., Kaufman & Kaufman, 2000). Therefore, one might be tempted to think that bilingualism hinders development or reduces the aptitude for learning in this domain, but several findings speak against this interpretation. First, bilinguals are not at a disadvantage on all language-based tasks. In a study with children from different socioeconomic backgrounds, bilinguals showed so-called “profile effects”, where a relative disadvantage compared to monolinguals was observed for vocabulary knowledge, but not for other abilities, for example, in the field of phonology (Oller, Pearson, & Cobo-Lewis, 2007). When it comes to metalinguistic skills, such as phonological and morphological awareness or understanding the arbitrariness of word-to-concept mapping, bilingual children often show advanced development (e.g., Barac & Bialystok, 2012, Eviatar & Ibrahim, 2000). In addition, although bilinguals across age groups tend to have smaller vocabularies in each of their languages, they show an advantage when it comes to learning new words (e.g. Bartolotti & Marian, 2012, Bartolotti, Marian, Schroeder, & Shook, 2011, Kaushanskaya, 2012, Kaushanskaya & Marian, 2009a, 2009b, Nair, Biederman & Nickels, in press, Wang & Saffran, 2014, Yoshida, Tran, Bentitez, & Kuwabara, 2011). How can these seemingly contradicting findings be explained? Unlike monolinguals, bilinguals’ learning capacities and time of exposure are distributed between two languages. For semantic concepts that are tied to a specific context, bilinguals may have acquired a lexical representation in one language but not the other, depending on individual characteristics of language use. Data from a study with school-aged children (ages 7-8 and 10-11) indicate that although bilinguals had less vocabulary knowledge within each language, whenever they did not know a word in one language they usually knew the translation equivalent, and their combined L1 and L2 vocabulary (the total amount of concepts for which either an L1 or L2 label was available) exceeded that of monolinguals (Oller et al., 2007). This finding suggests that differences in vocabulary knowledge are related to limited within-language exposure in bilinguals relative to monolinguals.

In regards to the difficulties bilinguals experience with lexical access, several alternative explanations have been proposed. The “weaker links” hypothesis also assumes a central role of limited within-language exposure for bilinguals relative to monolinguals. Specifically, it is suggested that because bilinguals necessarily use each of their languages less, de facto word frequency within each language is lower than estimated for monolinguals (both in regards of production and reception). Therefore, compared to monolinguals, the association between lexical representations and the semantic concepts they refer to is weaker, the baseline activation of lexical items is reduced, and items are less accessible for retrieval (Gollan & Acenas, 2004, Gollan et al., 2005a, Gollan et al., 2005b, Gollan et al., 2002, Gollan & Silverberg, 2001). Word frequency predicts the speed of lexical access in general, regardless of the language in question (e.g., Oldfield & Wingfield, 1965, Scarborough, Cortese & Scarborough, 1977). Thus, the weaker links hypothesis assumes that a universal mechanism accounts for a slow-down in lexical access independently of participants’ language background, and that within-language processing in bilinguals is not different from monolinguals.

On the other hand, bilinguals’ difficulties with lexical access might be due to the added cognitive load that results from parallel language activation and especially, cross-linguistic interference (see, e.g., Sandoval, Gollan, Ferreira, & Salmon, 2010). Given that lexical access is, in principle, non-selective, and under most circumstances the non-target language is co-activated when bilinguals engage in a language task (e.g., Kroll et al., 2012), retrieval load should be increased in bilinguals compared to monolinguals. Furthermore, although lexical items from both languages compete for selection, intrusions from the non-target language must be avoided, which requires a mechanism of interference control that might be time-costly (Sandoval et al., 2010). Both frequency- and interference-based accounts are supported by empirical evidence. To contrast the predictive value of the two hypotheses, one may test whether language status interacts with word frequency, as both make opposite predictions. According to the weaker links hypothesis, the bilingual disadvantage should be more pronounced for low-frequency compared to high-frequency words, as words in the lower frequency range are more sensitive to differences in frequency due to ceiling effects (see Griffin & Bock, 1998, Murray & Forster, 2004). On the other hand, bilinguals are more likely to possess both translation equivalents for high-frequency than for low-frequency words, and therefore, a larger bilingual disadvantage would be expected from an interference-based perspective. On the basis of this dissociation, evidence from naming supports frequency-based accounts (Gollan et al., 2008, Ivanova & Costa, 2008), whereas verbal fluency data points to a key role of parallel language activation and interference (Sandoval et al., 2010). In addition, both types of paradigms yield evidence for the occurrence of cross-language intrusions (Sandoval et al., 2010, for category fluency in young adults, Yan & Nicoladis, 2009, for naming in children). Other findings, such as equivalent naming times for cognates in bilingual and monolingual participants, are consistent with both perspectives (Gollan et al., 2008, Ivanova & Costa, 2008). Importantly, the two accounts are not mutually exclusive and frequency as well as interference-based mechanisms might contribute to the bilingual deficit in lexical retrieval. To the extent that the relative linguistic disadvantages observed for bilinguals reflect an increased processing cost due to language-co-activation, they relate back to the executive performance benefits discussed in the previous section. From this perspective, bilingual costs and benefits may in part go back to the same underlying mechanism and constitute traces of subtle processing differences in function of linguistic knowledge and history.

1.3 Variability in bilingual costs and benefits

The two previous sections summarized evidence for the cognitive consequences of bilingualism on language processing as well as extralinguistic executive control. The empirical landscape reveals a pattern of linguistic costs and executive benefits of dual language experiences (e.g., Bialystok, 2009), however, specific effects are not always replicable (e.g., Namazi & Thorardottir, 2011, Paap & Greenberg, 2013). As Kroll and Bialystok (2013) note in their outlook on the current state of research in this field, the formulation of categorical hypotheses, wherein tasks are classified as either executive or non-executive, and participants are classified as either bilingual or monolingual may in part be responsible for these inconsistencies. The following two sections highlight how a finer-grained consideration of task-related and participant-related characteristics may contribute to understanding the cognitive consequences of bilingualism in greater detail and resolve some of the seemingly contradicting outcomes.

1.3.1 Variability in bilingual costs and benefits: Task-related aspects

Task impurity problem

A fundamental problem of all cognitive research that is accentuated in the study of executive functions is the problem of operationalization. Testing hypotheses about something that cannot be observed directly (i.e., cognitive processes and abilities) depends on the extent to which experimental tasks tap into exactly those processes and abilities one is interested in. Putting aside the issue of reliability (that is, the degree of intra-individual variation due to non-systematic factors such as motivation, fatigue etc.), cognitive processes do not operate in a vacuum but in interaction with each other. Therefore, even the most well-defined and simple task cannot yield a pure measure of the intended target function. This problem, referred to as the “task impurity problem” is aggravated in executive function research where by definition, executive processes operate “on top of” other, non-executive processes which they direct and regulate (Burgess, 1997). In addition, as previously discussed (see section 1.1), executive processes and mechanisms are inseparably intertwined. For example, being able to inhibit distracting information necessarily requires maintaining or activating the task representation in WM, thereby drawing on WM resources. Conversely, monitoring the content of WM requires a mechanism of interference resolution to protect the content of WM. Therefore, performance on any task designed to measure a specific executive process such as, for example, inhibition, is systematically influenced by both other executive processes as well as domain-specific non-executive processes, and reflects these to a degree that is difficult to define. Although the implementation of well-defined and concise tasks can reduce the issue of task impurity, it is important to keep in mind that performance on an experimental task does not equate the process or ability it is intended to target (see also Kroll & Bialystok, 2013), and that different sources of variability contribute to a single task outcome. These issues have various consequences for the study of the cognitive effects of bilingualism. On the one hand, they complicate the localization of specific effects and their mediating mechanisms (sections 1.1 and 1.2), and what is more, they can make it very difficult to detect these effects at all.

Interaction of bilingual costs and benefits

On the other hand, it is important to keep in mind that bilingualism appears to affect cognitive processes in various domains differentially (see sections 1.1 and 1.2). Theorists have proposed a conceptual link between bilingual executive benefits and linguistic costs, and together, these effects speak to the mutual dependence and experience-based malleability of cognitive systems. However, only a handful of studies have looked at these distinct effects in a more systemic way. As argued above, even performance on relatively simple tasks depends on multiple processes. To the extent that a task draws on both executive and linguistic processes, putative costs and benefits would be expected to counteract each other (for a similar argument, see Bialystok, 2009), leading to what will look like a lack of between-group differences on the surface, but reflecting an interactive contribution of multiple underlying processes.

An example can be observed in two studies that compared verbal fluency in bilingual and monolingual participants. Luo, Luk and Bialystok (2010) examined the contribution of linguistic and executive resources to two verbal fluency paradigms, both of which draw on vocabulary knowledge and executive control, but to different degrees: while measures of category fluency are more closely related to vocabulary scores, letter fluency depends more critically on executive control. The sample consisted of a monolingual group and two bilingual groups, one of them showing the characteristic deficit in vocabulary knowledge that is often observed in bilinguals while the other one was matched to monolinguals in terms of vocabulary. By means of retrieval time-course analysis, the authors were able to extricate separate indices of vocabulary knowledge and executive control from participants' verbal fluency performance, and the three groups were compared on these two component processes as well as overall category and letter fluency. In this sample of young adult bilinguals, no differences between groups were observed for category fluency, however, participants' performance reflected superior executive control for both bilingual groups, lower vocabulary in the low-vocabulary bilingual group, and only the high-vocabulary bilingual group showed superior letter fluency compared to the two other groups. In line with these findings, results from another study (Bialystok, Craik, & Luk, 2008b) suggest that bilinguals may either outperform or underperform monolinguals on measures of verbal fluency, depending on the executive demands of the task and whether or not groups are matched for vocabulary knowledge. Similarly, bilingual children and adults showed traces of enhanced executive control compared to age-matched monolinguals on a memory task involving proactive interference, although the overall level of recall success was similar in both groups (Bialystok & Feng, 2009), and bilingual adults in particular showed higher recall after the difference in vocabulary knowledge was statistically controlled for.

The difficulty to identify distinct underlying processes and explore multiple modulatory factors increases with the complexity of the target construct. Working Memory is an example of a more multi-faceted construct (e.g., Baddeley, 1986, 1996, Gathercole, Pickering, Ambridge & Wearing, 2004) whose components may be differentially affected by distinct effects – costs and benefits – associated with bilingualism (Luo, Craik, Moreno, & Bialystok, 2012). The same may be true for literacy skills such as reading comprehension or mathematics that are known to rely on both executive as well as linguistic component processes (e.g., Abedi & Lord, 2001, Cain, Oakhill, & Bryant, 2004, Lee, Ng, & Ng, 2009, Oakhill, Cain, & Bryant, 2003, Pasolunghi, Cornoldi, & De Liberto, 1999, Shaftel, Belton-Kocher, Glasnapp, & Poggio, 2006, see also, Bialystok, 2001). From a perspective of practical relevance, it is of particular interest whether the effects of bilingualism extend to the acquisition of such complex literacy skills, as well as Working Memory as an important predictor of these skills and academic attainment in general (e.g., Gathercole, Pickering, Knight & Stegmann, 2004, St. Clair-Thompson & Gathercole, 2006).

Two studies yield indirect evidence for the interaction of executive and linguistic processes on working memory performance and mathematical skill in non-balanced bilingual children at the elementary school level. In regards to WM, emerging bilinguals outperformed their monolingual age-peers on both visuo-spatial and verbal tasks as long as the executive load was high, and vocabulary as well as SES, where bilinguals were at a disadvantage, were statistically controlled (Blom et al., 2014). Regarding mathematical skills, bilinguals were outperformed by monolinguals on language-based math problems, but this bilingual deficit was visibly attenuated when executive demands of the task were increased (Kempert, Saalbach, & Hardy, 2011). In these studies, bilinguals were tested in their weaker L2 and were compared to monolinguals performing the same tasks in their L1. It is therefore unclear to what extent the findings (especially in regards to linguistic costs) can be attributed to bilingualism per se and to what extent they reflect bilinguals' status as L2 learners instead.

In sum, these findings illustrate that underlying processing differences can lead to similar overall attainment in bilingual compared to monolingual participants, and that bilinguals can, to a certain degree, compensate linguistic deficits through increased executive control on both relatively simple and more complex cognitive tasks. In addition, the summarized studies highlight ways to deal with task impurity problems: in a situation where task performance is subject to multiple counteracting effects, interpreting the constellation of outcomes on several carefully selected tasks is more informative than interpreting between-group differences – or lack thereof on an individual task. An alternative approach to separating distinct sources of variability is illustrated by a study on the cognitive consequences of bilingualism in children from low socioeconomic backgrounds (Engel de Abreu et al., 2012). Conducting principal component analysis (PCA), the authors were able to extract two independent components from a battery of WM, reasoning, and executive function tasks, which they named executive control and representation. Based on principal component scores, bilingual children showed enhanced executive control but equivalent representation abilities compared to age-matched monolinguals. Reducing the overall variance to two components and separating the representational and executive aspects shared across tasks allowed the authors to extract a purer, and at the same time, potentiated measure of executive control while also reducing error accumulation due to multiple testing.

1.3.2 Variability in bilingual costs and benefits: Participant-related aspects

Thus far, it has been argued that dual language experiences may shape the way individuals process both linguistic and nonlinguistic information, modulating the interaction between cognitive systems, and that detecting the consequences of this reconfiguration in the form of linguistic costs and executive benefits may depend on systematic task selection and statistical analysis. Having argued why the categorical conceptualization of experimental paradigms as either executive or non-executive might be problematic, the logical next step is to examine the implications of conceptualizing bilingualism as a dichotomous, categorical variable. Bilingualism and monolingualism are not categorical variables, and bilingual environments and experiences may vary in a multitude of factors (see Luk & Bialystok, 2013). The most straightforward way to account for the variability across between bilingual populations and organize the body of data on executive control accordingly might be by conceptualizing bilingualism as a continuum from a maximally monolingual to a maximally bilingual pole, but evidently, there are different ways to approximate this dimension.

Varying degrees of bilingualism

Recent studies trying to capture how the degree of bilingualism might relate to cognitive performance have mostly quantified bilingualism in terms of either the age of acquisition (AoA) or proficiency of the L2. In terms of AoA, the idea seems intuitive that executive advantages might be constraint to those cases where bilingualism has been acquired at a young age, at a stage where both the language system and the executive system are undergoing dramatic developmental changes. However, results have been somewhat inconclusive with some observing executive advantages for early bilinguals but not late bilinguals (Kapa & Colombo, 2013, Luk, de Sa, & Bialystok, 2011), others reporting enhanced executive control for both early and late bilinguals (Pelham & Abrams, 2013) and yet others observing *different* executive benefits for early vs. late bilinguals, compared to monolinguals (Tao et al., 2011). Similarly, defining the degree of bilingualism in terms of either absolute L2 proficiency or balance of L1 and L2 proficiency, some have reported increased executive control for bilingual children (Iluz-Cohen & Armon-Lotem, 2013, Thomas-Sunesson et al., in press) or young adults (Singh & Mishra, 2012, Tse & Altarriba, 2015, Vega & Fernandez, 2011) who had reached higher levels of proficiency in their second language, compared to less proficient bilinguals, while others have found no effect of L2 proficiency on executive control performance (Dong & Xie, 2014). A particularly well-controlled recent study showed enhanced executive control across multiple tasks targeting different executive mechanisms for non-balanced bilinguals who had acquired their second language as late as young adulthood (Vega-Mendoza et al., 2015). Thus, neither the age of L2 acquisition nor the level of L2 proficiency achieved seem to present a deterministic constraint to the cognitive consequences of bilingualism. Although the age from which an individual has started to use a second language and the proficiency level they have reached evidently affect the way language is processed, some have even argued that late bilinguals may, in fact, be more likely than early bilinguals to show cognitive adaptation effects in light of these differences (Duñabeitia & Carreiras, 2015).

In addition, another undeniably important indicator of the degree of an individual's bilingualism is their language use or activity. Theoretical accounts of the cognitive consequences of bilingualism revolve around the coordinated and active use of multiple languages (e.g., Bialystok, 2001, 2009, Green & Abutalebi, 2013, Stocco et al., 2014), and the degree of active bilingualism likely interacts with formal proficiency and age of acquisition of the L2 in determining the attentional demands of multiple language use (see De Bruin & Della Sala, 2015, Yang, Hartanto, & Yang, 2015, Yow & Li, 2015). In fact, recent evidence suggests that executive advantages might revert in early bilinguals who no longer actively use both languages (Bogulski et al., 2015). Yet, this variable remains largely understudied and may present a potential confound in research opting for a definition of the degree of bilingualism in terms of proficiency or age of acquisition.

Cognitively demanding aspects of dual language control

Another (usage-based) possibility to distinguish bilingual populations is in terms of the presence of specific cognitive and linguistic operations within bilinguals' language control inventory that have been speculated to cause the adaptive effects in question. Here, the idea is that increased executive control in bilinguals is associated not with the knowledge of multiple languages per se, but with more specific factors that may be associated with dual language use and that pose a challenge to the executive system. Comparing different groups of bilinguals, Elmer, Hänggi and Jäncke (2014) found that grey matter density in cognitive control areas, a neurostructural marker of cognitive adaptation, was modulated by the specific executive, linguistic and articulatory demands of participants' dual language experience. Mainly two factors have been discussed as potential sources (and conversely, constraints) of the cognitive effects of bilingualism: cross-linguistic competition and language switching (e.g. Bialystok, 2001, 2009, Green & Abutalebi, 2013, Stocco et al., 2014, Morales et al., 2013, 2015). Importantly, neither one of these factors is necessarily present in all bilingual populations (Green & Abutalebi, 2013), which could explain why bilingual advantages are not always observed. Speaking to the role of cross-language (lexical) competition, longitudinally emerging executive advantages in bilingual toddlers are predicted by increase in translation equivalents at the individual level (Crivello et al., 2016). This finding would be expected if cross-linguistic competition conditions the executive advantage, because competition between lexical representations of two languages can only occur if a bilingual possesses both translation equivalents as part of their lexicon. In addition, there is evidence that due to the noncompetitive relationship between spoken and signed language representations (Emmorey, Borinstein, Thompson, & Gollan, 2008), bimodal bilinguals do not seem to show the same executive advantages as unimodal bilinguals (Emmorey, Luk, Pyers, & Bialystok, 2008).

In regards to the role of language switching, comparing highly proficient bilinguals who reported frequently switching between languages to equally proficient non-switchers and less proficient bilinguals, a recent study found a performance advantage for the frequent switchers on two interference tasks, leading the authors to conclude that language switching is key in determining whether a bilingual will show an executive advantage, with L2 proficiency playing a less prominent role (Verreyt, Woumans, Vandenalotte, Szmalec, & Duyck, 2015). Others have found beneficial effects of language switching on executive control in the context of task switching paradigms (Prior & Gollan, 2011, Soveri, Rodriguez-Fornells, & Laine, 2011, Wiseheart et al., 2016).

In sum, researchers have recently started to approach bilingualism and its cognitive consequences in a much more differentiated way and have identified a number of factors that might condition the effects that have been described in the executive advantage literature. Although much research remains to be done regarding the systematicity of the observed effects, an important insight from these studies is that multiple modulatory variables contribute to the cognitive demands of dual language use. Yet, many theoretical accounts remain largely unidimensional (see, e. g., Bialystok & Majumder, 1998, Colzato et al., 2008, Costa et al., 2009, Hernández, Costa & Humphreys, 2012 Hilchey & Klein, 2011, Morales et al., 2013, Prior, 2012, Stocco Yamasaki, Natalenko, & Prat, 2014). Alternative proposals regarding the nature of the putative bilingual executive advantage generally seem to part from the premise that a universal encompassing mechanism is responsible for the executive advantages reported in different studies. Critics have followed the same path by suggesting that researchers in the field seek maximal convergence through defining a specific, circumscribed aspect of executive control that should be modulated by speaking two languages and demonstrate that bilinguals outperform monolinguals on multiple tasks tapping this process (e.g., Paap & Greenberg, 2013). However, performance differences between monolingual and bilingual samples on cognitive tasks are thought to reflect cognitive adaptation to the *specific* cognitive demands of language processing in all participants (e.g., Bialystok, 2001, 2009, Stocco et al., 2014), and it is important to note that bilinguals may differ not only in the amount but also in the type of executive control they need to rely on in their daily interactions (Green & Abutalebi, 2013).

<u>Adaptive control hypothesis</u>

A theoretical framework that develops this idea in more detail is the adaptive control hypothesis (Green & Abutalebi, 2013). According to this framework, cognitive adaptation effects in bilinguals are determined by the linguistic environment. This idea is in line with the principles of cognitive plasticity, according to which adaptive changes in structure and function are always driven by the environmental demands (Lövdén et al., 2010). Three types of bilingual interactional environments are schematically described, namely *single language contexts*, where bilinguals are required to use one of their languages but not the other one, *dual language contexts*, where bilinguals use both languages but with different speakers, and dense *code-switching environments*, bilinguals use both languages indiscriminately to address other speakers, so that a language is neither associated with a specific context nor with specific speakers. A further assumption is that although all bilinguals experience parallel language activation, this only implies cross-language interference (and subsequently increased executive demands compared to monolinguals) if there is a designated target language at any given moment, as is the case in single and dual language environments. In code switching environments, linguistic representations from both languages are not in a competitive relationship because potential interlocutors are highly proficient in both languages, and therefore, intrusions from an unintended language do not cause a lapse in communication. In addition, only bilinguals in dual language contexts are required to switch languages "on command" because the interactional target language may change at any given moment (evidently, code switchers carry out language switches, but in the context of this framework, it is assumed that these language switches are internally paced and do not present increased control demands).

Accordingly, bilinguals in different language environments adapt to different control demands, particularly in regards to mechanisms that subserve the balance between cognitive stability vs. flexibility (Bilder, 2012). Thus, it is posited that efficient communication within single language environments requires mostly language control processes that stabilize a current task setting. These might include proactive mechanisms that bias internal and external perception and attention towards target language representations, thereby reducing interference from the non-target language pre-emptively, as well as reactive mechanisms that manage interference as it occurs, for example via inhibition of the non-target representation. Bilinguals who are used to communicating in single language environments are thus expected to show adaptive effects in processes such as conflict monitoring or interference resolution. Communication within dual language contexts recruits the same control mechanisms as described for single language environments, but to a larger degree, because the overt presence of the non-target language within the same context increases interference (Christoffels , Firk & Schiller, 2007, Gollan, Schotter, Gomez, Murillo, & Rayner, 2014). In addition, bilinguals in dual language contexts need increased flexibility to disengage the current task set, engage a new task set, and immediately stabilize the new task set against interference to manage recurrent changes of the target language (Green & Abutalebi 2013). The control mechanisms associated with code switching environments are described in less detail, but the quintessence of the adaptive control framework is that different control configurations are adaptive within different interactional environments. In addition, aspects of the individual language background (such as L2 proficiency, age of acquisition and especially active immersion) coexist and interact with the communicational language control requirements of the environment (such as the need for cross-language interference resolution or language switching) to determine the demands for executive language control. Thus, bilinguals who coordinate and control multiple languages in different ways throughout their daily lives may show different patterns of enhanced executive control, and not all bilinguals will show any executive benefits at all. Although the adaptive control hypothesis does not discuss consequences in the linguistic domain, a similar degree of selectivity might apply to the linguistic costs of bilingualism. A number of testable hypotheses can be formulated on the basis of the adaptive control hypothesis. Although many of the data discussed above seem to align with the postulates of the framework – for example, the observation of bilingual benefits on task switching paradigms in function of language switching habits (and an overall less frequent observation of these particular benefits) - more research is needed.

1.4 The role of domain-general executive resources in language control

One of the central assumptions upon which this work is based is the notion that domain-general cognitive-executive resources are employed for the control and regulation of language processes, especially when control demands are increased. The prediction of a bilingual executive advantage follows from, and depends on, precisely this assumption. But what is the evidence for a convergence of linguistic and non-linguistic control functions, and does it justify the interpretation that bilingualism is, in fact, associated with increased control requirements? The following provides a review of how language control is exercised in monolinguals and in bilinguals - when they process their second (or weaker) language, their native (or dominant) language, and when they process multiple languages at once.

Before turning to the discussion of empirical evidence, it is important to define what we mean by “control functions” of language. Evidently, real-life linguistic functioning involves many routine as well as non-routine processes or behaviors. Processes such as lexico-semantic access, phonological and syntactic analysis, articulatory planning and to some degree even their coordination into higher-order language functions, etc. are highly automatized in skilled speakers (e.g., Schmid, in press). On the other hand, all of these processes can be subject to (effortful) control. For example, controlled, non-routine processing is necessary to analyze meaning in the context of word play, metaphor, or simply, complex and dynamic discourse. On a micro-level, basic language functions require control and regulation when automatic processes cannot produce an unambiguous solution, for example, when competition arises between different lexical items at the phonological level (e.g., Andruski, Blumstein, & Burton, 1994, Luce & Pisoni, 1998, McClelland & Elman, 1986, Norris, 1994), or between alternative interpretations of syntactic structures (e.g., Spivey-Knowlton & Tanenhaus, 1994). To enable adaptive functioning in everyday life, there needs to be an "executive control of language". Thus, the question is not whether cognitive control processes are involved in language, but rather, whether, and to what extent language control draws on the same resources as non-linguistic executive control. Evidence for total or partial overlap between linguistic and non-linguistic control functions goes against purely modular views, whereby language is encapsulated from other cognitive functions. Studies that investigate these questions tend to be correlative, as they seek to establish a link between linguistic and domain-general control by showing that participants' performance on language control tasks can be predicted from individual differences in established measures of domain-general cognitive control, or that both types of control are associated with activation of the same neuroanatomic correlates (e.g., Blumenfeld & Marian, 2011, Marian, Chabal, Bartolotti, Bradley, & Hernandez, 2014).

Executive control of single language processing in monolinguals

From a developmental perspective, language and domain-general executive control are highly interdependent. Developmental milestones in the domain of cognitive-executive control, such as the emergence of cognitive flexibility (or set shifting) in the preschool years, depend on the acquisition and flexible use of language skills (e.g., Deák, 2003, Jacques & Zelazo, 2005) and vice versa (e.g., Khanna & Boland, 2010, Woodard, Pozzan, & Trueswell, 2016). This close-knit relationship between language and domain-general executive control carries on throughout the life-span. There is evidence to suggest that domain-general inhibitory control plays a role in conflict resolution when alternative representations are activated and compete for selection across levels of linguistic complexity. For example, individuals who achieve more efficient inhibition on both linguistic and non-linguistic interference tasks are better at resolving phonological competition and consequently show enhanced phonological representations (Lev-Ari & Peperkamp, 2014, Taler, Aaron, Steinmetz, & Pisoni, 2010). Similarly, the ability to resolve syntactic ambiguity in the context of garden path sentences emerges in close temporal correspondence with the development of inhibitory control (e.g., Hurewitz, Brown-Schmidt, Thorpe, Gleitman, L., & Trueswell, 2000, Kidd & Bavin, 2005, Weighall, 2008, Trueswell, Sekerina, Hill, & Logrip, 1999), and has been found to be significantly improved after training in non-linguistic conflict resolution (Hussey & Novick, 2012). At yet a higher processing level, the successful comprehension of metaphor relies on an inhibitory mechanism that reduces the activation of literal meaning, and that is likely to be of domain-general nature (e.g., Columbus, Sheikh, Côté-Lecaldare, Häuser, Baum, & Titone, 2014, Glucksberg, Newsome, & Goldvarg, 2001). With these data in mind, it comes as no surprise that in both children and adults, complex linguistic skills such as text comprehension show covariation with executive control functions including inhibition and working memory (e.g., Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014, Borella, Ghisletta, & Ribaupierre, 2011).

Executive control of single language processing in bilinguals' L1

Thus, evidence is plentiful that monolinguals processing their one and only language experience linguistic competition and conflict, the resolution of which appears to involve domain-general executive resources. One might ask, then, what is special about bilingualism? Theoretically, an obvious answer might be that the sheer number of potential competitors is approximately doubled in bilinguals. This is the case even if we consider only processing one target language (unilingual processing). Cross-language competition in bilinguals comes in addition to the within-language competition that monolinguals experience, and the situation that two linguistic forms exist for a concept one wishes to express (at the lexical level: synonyms within-language, translation-equivalents between-language) is much more common in bilinguals. Overall, it seems that competition between linguistic representations would be more extensive in bilinguals than in monolinguals, even in the case of unilingual processing. It is important to note that there are factors that modulate the selectivity of lexical access in bilingual speakers: co-activation of the non-target language is modulated by variables such as contextual cues (e.g. visual input regarding speaker identity, see Molnar, Ibañez, & Carreiras, 2015, Li, Yang, Scherf, & Li, 2013). However, such a downregulation of non-target language activation does not reduce the putative need for executive control, but rather, it reflects the fact that in language control, as in general executive control, control processes are multifaceted, dynamically coordinated, and do not work in isolation. Specifically, the detection and integration of relevant contextual cues and their ability to bias lexical activation towards the current target language implies an efficient interaction of reactive and proactive control processes as previously described (see section 1.1).

As is the case within-language, cross-language competition and conflict may arise on different levels of linguistic representation (that is, phonemes, lexemes, or even syntactic structures from both languages might compete, see Kroll et al., 2012), although most research has focused on lexical processing. In line with findings regarding within-language competition, it has been suggested that the resolution of cross-linguistic interference depends on inhibitory control mechanisms (Green, 1998, see also Paradis, 1993, 2001). An example can be observed in the processing of interlingual homographs, words that have the same form but different meaning in two languages. Semantic access in the case of homographs involves inhibition of the non-relevant meaning (Macizo, Bajo, & Martin, 2010, Martin, Macizo, & Bajo, 2010) and individual susceptibility to cross-linguistic semantic interference is correlated with general inhibitory and executive abilities (Lev-Ari & Keysar, 2014, Pivneva, Mercier, & Titone, 2014).

It is difficult to directly compare the executive control demands of bilingual vs. monolingual language processing, but a few studies have reported interesting findings in this regard. Parker Jones and colleagues (2012) found that picture naming in the L1 was accompanied by greater activation of several left-lateralized frontal and temporal areas including the superior temporal gyrus (STG) in bilinguals relative to monolinguals, suggesting greater retrieval load in the former group. A similar study with bimodal bilinguals (L1-Chinese, L2-Chinese Sign language) found additional activation in the right superior occipital gyrus (ROSG), associated with the automatic activation of signed words, as well as the right supramarginal gyrus (RSMG) and right superior temporal gyrus (RTG) in bilinguals compared to monolinguals, which the authors linked to increased cognitive control demands (Zou et al., 2012). Bilinguals in the latter study had learned sign language late in life, suggesting an effect of the L2 on an already established L1. Furthermore, Marian and colleagues explored the role of domain-general executive (inhibitory) control in the resolution of within-language phonological competition in two experiments. Both studies compared monolinguals and bilinguals in their L1. In one experiment, they found that the ability to suppress phonological competition was correlated with performance on a nonlinguistic Stroop task in bilinguals, but not monolinguals, as indicated by reaction time, accuracy, and eyetracking data, although both groups displayed the same degree of competition (Blumenfeld & Marian, 2011). Findings regarding the underlying neural substrates were consistent with these results. Specifically, increased activation of a domain-general executive network including the anterior cingulate (ACC) as well as the superior, middle, and inferior frontal gyrus (SFG, MFG, IFG) predicted successful resolution of phonological competition in bilinguals, but not monolinguals. For the latter group, only a correlation between competitor inhibition and activation of the MFG was significant. However, despite the lack of individual difference covariance, monolinguals as a group showed reliance on the frontal executive network during competitor trials, reflected by increased activation of pertinent brain areas (ACC, left IFG, MFG and SFG). Bilinguals, on the other hand showed less overall cortical activation throughout task performance, and a downregulation of cerebellar and parahippocampal activation, potentially reflecting resource concentration on task-relevant processing streams (Marian et al., 2014). Combined, these results suggest that bilinguals and monolinguals manage linguistic competition differently. Domain-general executive control plays a role in both groups, but it seems to be employed in different ways. Specifically, i) the relatively reduced activation observed in bilinguals might reflect a greater automaticity in selecting between competing linguistic representations, whereas ii) stronger correlation between the resolution of linguistic conflict and non-linguistic conflict on the one hand, and activation of the frontal executive network on the other hand, suggest there is increased synchronization of domain-specific and domain-general control in this group. Both findings indirectly support the assumption that bilinguals experience linguistic competition more frequently.

Executive control of dual language processing in bilinguals

Support for the convergence of language control and domain-executive control extends further to situations where bilingual speakers use both languages within the same context. In fact, most research regarding language control in bilinguals and its relation to domain-general executive control has focused on dual language control in the case of language switching, perhaps due to the fact that additional control demands seem particularly obvious in this case. As previously argued (see section 1.3.2), language switching introduces several specific control demands. On the one hand, the need for inhibitory control is likely increased as the overt presence of multiple languages and constant change of the target language increase co-activation and competition from the non-target language (e.g., Gollan et al., 2014). Studies on language switching observe increased response latencies on trials where a language switch is required compared to trials where the language remains the same (e.g., Meuter & Allport, 1999, Costa & Santesteban, 2004). This finding mirrors the switch costs observed in non-linguistic task switching paradigms and reflects, to a certain degree, lasting inhibition of the current target language from the previous trial (Verhoef, Roeloefs, & Chwilla, 2009). Again, there is supporting evidence that this inhibitory control is domain-general in nature. General performance on a language switching task (Linck, Schwieter, & Sunderman, 2012), and the frequency of cross-language intrusions in particular (Festman & Münte, 2012, Festman, Rodriguez-Fornells, & Münte, 2010) predict inhibitory and conflict monitoring abilities measured by a range of non-linguistic interference tasks. In addition, switch costs in linguistic and non-linguistic task switching paradigms covary at the individual level (e.g., Prior & Gollan, 2011, Weissberger, Wierenga, Bondi, & Gollan, 2012). Importantly, divergent evidence shows that individual differences in susceptibility to cross-linguistic interference cannot be explained by language-specific variables such as linguistic competence or language context (Festman, 2012). In terms of the underlying neural correlates, Abutalebi and colleagues

(2011) identified the dorsal ACC as a common substrate of conflict monitoring in both language switching and a flanker interference paradigm. However, as argued above, language switching also involves a series of other mechanisms that enable flexibility, such as rapid release of inhibition and task reconfiguration. As one might expect, empirical overlap is considerably larger for non-linguistic task switching paradigms, which are also more similar conceptually. Based on a meta-analysis, switching between languages involves a fronto-parietal-subcortical network (Abutalebi & Green, 2008), and the same network also underlies non-linguistic executive control (Aron, Durston, Eagle, Logan, Stinear, & Stuphorn, 2007). Within this network, the lateral prefrontal cortex (PFC) supports sustained attention and proactive control in an ongoing task (e.g., Hyafil, Summerfield, & Koechlin, 2009, MacDonald, Cohen, Stenger, & Carter, 2000), and in bilingual language control, establishes global inhibition of the non-target language during single language blocks. The medial PFC, with the dorsal anterior cingulate cortex (ACC) and pre-supplementary motor area (pre-SMA) exerts performance monitoring. Whereas the ACC is activated when error or conflict are detected, the pre-SMA enables task re-configuration for an upcoming trial proactively through inhibition of active but no longer relevant actions or representations (Hikosaka & Isoda, 2010). In language switching tasks, the analogous role of the medial PFC is to monitor the context to detect the need for a language change and prepare for the change by exercising local inhibition (Guo, Liu, Misra, & Kroll, 2011). Parietal regions including the supramarginal gyrus (SMG) are involved in shifting attention to a new task (Braver, Reynolds, & Donaldson, 2003), and in bilingual language control, pulling attention away from the previously relevant, now irrelevant language and pushing it towards the new target language on switch trials. Finally, subcortical regions (in particular, the striatum including the caudate nuclei) modulate the relative strength of incoming signals within cortico-cortical connections and enable flexible and efficient selection between competing task or rule sets to control behavioral output (Stocco, Lebiere, & Anderson, 2010, see also

Stocco et al., 2014). Two recent studies compared the neural substrates of language switching and non-linguistic (color-shape and color-motion, respectively) task switching in the same participants and found substantial overlap within this network (De Baene, Duyck, Brass, & Carreiras, 2015, Weissberger, Gollan, Bondi, Clark, & Wierenga, 2015). On the other hand, in both studies, overlap was not complete suggesting that some aspects of switching might be more domain-specific, which confirms some previous findings (e.g., Calabria, Hernández, Branzi, & Costa, 2012, Weissberger et al., 2012). For example, Weissberger and colleagues (2015) found greater activation in the caudate, ACC and bilateral thalamus during linguistic vs. non-linguistic task switching, although all of these regions showed increased activation for both types of switching, compared to a control condition. In De Baene's study (De Baene et al., 2015), greater activation of prefrontal areas was observed during color-motion task switching, compared to language switching, which the authors attribute to the fact that stimulus-response mappings in the non-linguistic, but not the linguistic task were completely arbitrary, thereby posing greater demands on working memory and proactive control. It should be pointed out that there sometimes are substantial differences in the cerebral areas associated with bilingual language control in different studies (see García-Pentón, Fernández García, Costello, Duñabeitia, & Carreiras, 2015). For example, there seems to be disagreement regarding the role of the fronto-subcortical loop in bilingual language control. While some assign the caudate nuclei and their cortical projections a key role in switching between languages (e.g., Luk et al., 2011, Stocco et al., 2014) others propose that this loop mainly plays a role when a conversion of input-to-output language is required, as is the case in translation (Hervais-Adelman et al., 2011). In this context, De Baene and colleagues (2015) make the important point that differences in executive demands of the baseline task might result in failure to find subcortical activation in some studies. Such differences in task parameters and control conditions make it difficult to determine the exact degree of convergence between domain-general and domain-specific language control which by any means appears to be considerable.

<u>Executive control of single language processing in L2 learners</u>

Finally, another situation where bilinguals might experience increased control demands is in the context of second language acquisition. Processing of a non-native language is generally less automatic (see, e.g., Segalowitz & Hulstijn, 2009), especially at the beginning stages of acquisition. Compared to L1 processing, L2 processing tends to be slower and less accurate (Coderre, van Heuven, & Conklin, 2011), and is associated with a higher memory load (e.g., Abu-Rabia, 2003, Dussias & Piñar, 2010, Ransdell, Arecco, & Levy, 2001, for reviews, see Farmer, Misyak & Christiansen, 2012, Lewis, Vasishth & Van Dyke 2006). Subtle semantic connotations may not be accessed automatically (Degner, Doycheva &Wentura, 2012), and the functional categories of language that direct attention to certain aspects of a mental representation (such as time adverbials, or causal connectives) are processed less automatically and less flexibly in a second language (Segalowitz, & Frenkiel-Fishman, 2005, Slobin, 1996). In addition, when processing a weaker language, co-activation of the dominant language is much stronger than vice versa. Consequentially, L2 reading is more vulnerable to cross-linguistic interference compared to L1 reading (Yamasaki & Prat, 2014).

The latter finding can be accounted for by the revised hierarchical model (Kroll & Stewart, 1994), whereby words in the L1 are directly connected to the underlying semantic concept, whereas semantic access in a non-proficient L2 is mediated via lexical representations in the L1. Consequently, more inhibition is needed to control language output (Green, 1998). An example can be observed in language switching scenarios, where switch costs are larger when switching from a weaker to a more dominant language (e.g., Meuter & Allport, 1999). With increasing proficiency, processing becomes more native-like (e.g., Steinhauer, White & Drury, 2009), and levels of interlanguage co-activation and inhibition become more balanced (Costa & Santesteban, 2004). It therefore comes as no surprise that in second language learners, even unilingual processing of the L2 is associated with additional cognitive load. Thus, unilingual L2 naming, but not L1 naming, results in similar activation of the caudate as switching between languages (Ma et al., 2014), and a recent longitudinal study found that recruitment of brain regions associated with executive control (e.g., the ACC) for L1 and L2 processing is largest during the early stages of L2 acquisition (Grant, Fang, & Li, 2015).

The evidence discussed in this section suggests that domain-general executive resources support language processing across different linguistic scenarios. Convergence between linguistic and non-linguistic control functions is not unique to bilingualism, but is generally observed as the attentional load of a language task increases, as is the case in second language processing, bilingual switching and higher-order linguistic processing in monolinguals. However, the observations are generally in line with the predictions of section 1.3.2: executive demands for language processing differ in degree as well as type. Unilingual L1 processing is more resource-costly in bilinguals than monolinguals, and the same applies for bilinguals processing their L2 as opposed to their L1, or switching between languages, and different mechanisms or types of control predict specific language operations more reliably.

1.5 Organization and goals of the experimental series

As laid out in the introduction, accumulated data from the study of bilingualism and cognitive control points to a link between domain-general executive control and linguistic experience. There is evidence to suggest that linguistic control relies on domain-general executive resources particularly when control demands are increased, as is often the case in bilingual speakers (see section 1.4). Manifestations of this connection are evident in the form of performance differences between monolingual and bilingual participants on domain-general executive and language-based performance (see sections 1.1 and 1.2). However, specific effects are not always replicable (see, for example, De Bruin, Treccani, & Della Sala, 2015, Valian, 2015), suggesting that the relation between the language use and executive control is much more complex than previously assumed. Differences at the task or process-level and at the participant-level might present boundary conditions that modulate this relationship and its detectability in experimental settings but evidence in this regard is still very limited. Further research is needed to extract systematic patterns of variability from the overall body of data.

The first experimental series (Experiment 1 and 2) will focus on the interaction of bilingual costs and benefits in different task domains. In Experiment 1, we examine the developmental course of verbal Working Memory in emergent bilingual compared to monolingual children, and Experiment 2 will focus on L1 literacy acquisition. As previously argued (see section 1.2), due to their complexity and multifaceted nature, WM and literacy skills may be subject to multiple counteracting effects, and we will explore various possibilities of dealing with problems of task impurity in the context of bilingual costs and benefits. To understand how underlying processing differences contribute to overall performance, in Experiment 1, we use two tasks that combine demands for domain-general executive control as well as language-based processes, but rely on these respective processes to different degrees: an n-back task with letters (where executive demands are particularly high) and reading span (relying more heavily on linguistic processing compared to the n-back) and consider the overall pattern of results. In Experiment 2, we evaluate children at the level of complex skill (i.e., text-level reading comprehension), as well as underlying basic cognitive and linguistic components identified by means of Principal Component Analysis, thereby identifying independent sources of variance within the same tasks. We will be looking at this issue in the context of L2 immersion education, an educational approach that has been gaining popularity over the last years as an alternative path to bilingualism that is open to children from monolingual homes and communities.

The second experimental series (Experiment 3 and 4) aims to ascertain to what extent individual factors determine the degree and type of cognitive adaptation effects in bilingual participants. We will be focusing on characteristics of bilingual language use, namely the degree of active immersion in the L2 and language switching habits in late, non-balanced bilinguals. In Experiment 3, we test the effects of bilingual immersion and language switching longitudinally, while Experiment 4 adopts a cross-sectional design. In the spirit of the adaptive control hypothesis (Green & Abutalebi, 2013) whereby cognitive adaptation effects in bilinguals are selective and specifically usage-based, we will assess markers of executive control that contribute towards cognitive stability (i.e., conflict monitoring and interference solution) and flexibility (i.e., switch costs and mix costs). Although age of L2 acquisition certainly modulates the cognitive demands associated with dual language control there is evidence to suggest that cognitive benefits associated with bilingualism are not per se limited to crib bilingualism (see, e.g., Bak et al., 2015, Nicolay & Poncelet, 2015). Thus, we aimed to keep this variable constant and focus on the cognitive effects of a second language acquired later in life.

Finally, in the third experimental series (Experiment 5), we will explore the role of individual differences in executive control abilities in L1 and L2 processing in young adult bilinguals. As previously discussed, the degree and nature of executive mechanisms recruited to process language may vary across different linguistic operations. To ensure a high level of ecological validity, we will contrast L1 vs. L2 processing at the text-level. More specifically, we will first compare high-level semantic processes, namely inference generation and revision, in the L1 and L2. Secondly, we will explore to what extent individual differences in cognitive control, on the one hand, and L2 proficiency, on the other hand, predict variance in the integrity and efficiency of these processes in both languages. To understand the varied nature of executive resources aiding the different linguistic processes bilinguals engage in, we will consider the role of reactive and proactive cognitive control. Participants in this study were late bilinguals who had reached a high level of proficiency in their L2 that was close to native-like in many aspects.

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Chapter II

Experimental section

Experimental Series I (Experiments 1 & 2)

Experiment 1. Emergent Bilingualism and Working Memory development in School-Aged Children[4]

The present research explores working memory (WM) development in monolingual as well as emergent bilingual children immersed in an L2 at school. Evidence from recent years suggests that bilingualism may boost domain-general executive control, but impair non-executive linguistic processing. Both are relevant for verbal WM, but different paradigms currently in use vary in the degree to which they reflect these sub-processes. We found that only younger immersion students outperformed monolinguals on the n-back task, a measure of executive WM updating, but showed a relative deficit in L1 rapid naming, and to a lesser degree, reading span scores. Age effects suggest that rather than ultimate performance levels, bilingualism alters the developmental course of WMprocesses. We conclude that emergent bilingualism may modulate WM development in school-aged children at the sub-component level, but detecting this modulation is contingent on task selection.

[4] This experiment has been accepted for publication as Hansen, L. B., Macizo, P., Duñabeitia, J. A., Saldaña, D., Carreiras, M., Fuentes, L. J., & Bajo, M. T. (in press). Emergent bilingualism and working memory in school-aged children. *Language Learning.*

Bilingualism is among the factors that can affect cognitive development, slowing or accelerating the acquisition and maturation of particular cognitive skills. While certain lags or deficits have been observed in the realm of language development and linguistic processing, the development of executive functions may benefit from multiple language competence and use (for a review, see Bialystok, 2009). Until recently, research on the cognitive consequences of bilingualism had been based almost exclusively on highly proficient and relatively balanced bilinguals who had acquired both languages early in life (before starting school) at home or in the community (see Adesope, Lavin, Thompson & Ungerleider, 2010, Bialystok, 2009, Hilchey & Klein, 2011). Recent research, however, suggests that if the immersion duration has been sufficient, the beneficial effect bilingualism has on executive control may extend to second language learners attending bilingual immersion schools (Nicolay & Poncelet, 2013, 2015). Immersion schooling, where the foreign language is not just the subject, but the medium of instruction, provides children from monolingual homes and communities with the opportunity for a bilingual education and is thus becoming increasingly popular. In what way this “path” to bilingualism affects the development of cognitive skills and abilities is therefore of critical importance. Here we aim to explore the development of working memory (WM) through school age in monolingual children and children who are in the process of becoming bilingual via attendance of an immersion school.

WM is key to the development of complex cognitive skills such as mathematics (Raghubar, Barnes & Hecht, 2010) and reading comprehension (Carretti, Borella, Cornoldi & de Beni, 2009), and is a predictor for academic attainment (Gathercole, Pickering, Knight & Stegmann, 2004). It is thus unsurprising that researchers have started to explore the consequences of bilingualism on WM development (e.g., Engel de Abreu, 2011, Morales, Calvo & Bialystok, 2013, Namazi & Thorardottir, 2010). However, to our knowledge, the existing research has not been extended to second language learners undergoing bilingual immersion.

The notion of a “bilingual cognitive advantage” arises from cumulated evidence that bilinguals excel on tasks that rely heavily on executive control (e. g., Adesope et al., 2010, Bialystok, 2001, Bialystok, 2009). It has been suggested that the origin of this phenomenon lies in the parallel language activation that arises during bilingual speech production and comprehension (e.g., Thierry & Wu, 2007, Van Hell & Dijkstra, 2002) resulting in between-language interference which requires resolution. Controlled attention for bilingual language processing has been shown to be mediated at least partially by domain-general executive control mechanisms (for a meta-analysis, see Luk, Green, Abutalebi & Grady, 2012), and the constant recruitment of these mechanisms during bilinguals’ standard, everyday language processing is thought to render bilingualism a type of lifelong cognitive training that generalizes to executive processes beyond the linguistic domain (e. g. Bialystok, 2001). More recently, some authors have reported failures to replicate bilingual advantages in executive control (Antón et al., 2014, Duñabeitia et al., 2014, Namazi & Thorardottir, 2010, Paap & Greenberg, 2013), suggesting that perhaps this universal account lacks precision, and that the outcome of the between-group comparisons may depend on additional factors such as task-specific demands, bilingual population, or executive process in question.

In terms of specific target executive functions and mediating processes, the overall pattern of results is somewhat difficult to interpret because, for one, no single valid model of executive functions exists. A popular account that has often been referred to in the bilingual advantage literature identifies shifting or switching attention between tasks or mental sets (“Shifting”), updating and monitoring of representations in WM (“Updating”), and controlled inhibition of prepotent responses (“Inhibition”) as distinguishable, key mechanisms of executive control (Miyake, Friedman, Emerson, Witzki & Howerter, 2000). The components work in inseparable unison during task performance. From this theoretical perspective, WM is closely related to executive functioning, especially its updating component, as it refers to the online storage and manipulation of information (Baddeley & Hitch 1974) and provides the capacity for the maintenance of goal-related information necessary to coordinate task-relevant processes (Miyake et al.,, 2000). The conceptual overlap between WM and executive control is corroborated empirically by virtue of a close reciprocal relationship between measures of WM and executive control (McCabe, Roediger, McDaniel, Balota & Hambrick, 2010).

However, WM entails both executive and nonexecutive components or subprocesses (Baddeley & Hitch, 1974, Gathercole, Pickering, Ambridge & Wearing, 2004). Measures of WM differ in the relative degree to which they draw on domain-general executive control or domain-specific verbal or visuo-spatial storage. To assess WM performance, many researchers refer to either complex span procedures like reading span or operational span (Daneman & Carpenter, 1980), which combine recall with a secondary task, or versions of the n-back task (Cohen et al., 1997), where participants are required to evaluate sequentially presented stimuli for a match at a given lag (1-back, 2-back or 3-back). Both families of tasks tap into the updating and monitoring aspect of WM (Schmiedek, Hildebrandt, Lövdén, Wilhelm & Lindenberger, 2009). However, while complex span paradigms provide a more balanced measure of executive processing and short-term storage capacity (e.g., Bayliss, Jarrold, Gunn & Baddeley, 2003), the n-back task is thought to mainly reflect the updating component of executive functioning (Cohen et al., 1997, Miyake et al., 2000).

Beyond task-specific demands, separate WM components show independent developmental curves in school-aged children (Gathercole et al., 2004) and may be modulated differentially by developmental factors like bilingualism. This is crucial when exploring bilingual effects on WM because developmental bilingualism may come with costs in the linguistic domain. For example, monolinguals tend to score higher on tests of receptive or productive vocabulary than age-matched bilingual toddlers (Poulin-Dubois, Bialystok, Blaye, Polonia & Yott, 2012), preschool and school-aged children (e.g., Bialystok, Luk, Peets & Yang, 2010), and adults (e.g., Bialystok & Luk, 2012), and bilingual children and adults show more difficulties and slower reaction times in lexical access and lexical retrieval (e.g., Ivanova & Costa, 2008, Yan & Nicoladis, 2009). Importantly, this phenomenon extends to bilinguals' L1 and can be observed in sequential bilinguals after being immersed in a weaker L2 (Linck, Kroll, & Sunderman, 2009). Thus, while domain-general executive processes operating on WM may benefit from a general executive advantage, domain-specific verbal storage may be negatively affected by linguistic costs (Luo, Craik, Moreno & Bialystok, 2012). In sum, WM performance in bilinguals may be influenced by two counteracting effects that cancel each other out, ultimately placing bilinguals at the same overall level as their monolingual peers (Bialystok & Feng, 2009).

Existing research into bilinguals' WM performance reflects this ambiguity. Generally speaking, superior bilingual-to-monolingual performance tends to be observed when the relative executive demand is high. For example, on a variation of the Simon task that combined varying demands for WM and conflict resolution, five- and seven-year-old bilinguals were better able to handle increased WM load than monolinguals of the same age, even in the absence of conflict (Morales et al., 2013). In addition, bilingual participants of both age groups outperformed their monolingual peers on (complex) visual WM span. Regarding verbal updating, Carlson and Meltzoff (2008) reported a bilingual advantage once socioeconomic status and verbal abilities - where bilinguals were at disadvantage – had been statistically controlled for. On the other hand, no differences were observed when comparing bilingual and monolingual preschool children, school-aged children, adolescents or young adults on verbal, visuo-spatial, or symbolic memory (Bonifacci, Giombini, Bellocchi, & Contento, 2011, Engel de Abreu, 2011, Namazi & Thorardottir, 2010). All of the latter studies used simple span procedures, adding only minimal manipulation of the digits retained in WM (e. g., backwards span), and thus relatively minor executive demands (see Engle, Tuholski, Laughlin & Conway, 1999). This factor, in combination with putative linguistic disadvantages in bilinguals, may account for the mixed pattern of results.

Few studies have tried to extend these findings to second language learners attending bilingual immersion schooling (emergent bilinguals). In fact, the research by Carlson and Meltzoff (2008) has been the only one to assess this particular subgroup on a WM updating task. In terms of other aspects of executive functioning, the limited number of studies that exists seems to suggest that an executive advantage may emerge, but is constrained by how long a child has been immersed in the L2. Thus, compared to age-matched monolingual controls, no between-group differences emerged for children after 6 months (Carlson & Meltzoff, 2008), or 12 months of bilingual immersion (Poarch & van Hell, 2012). However, after having undergone bilingual immersion for three years, a group of eight year old emergent bilinguals outperformed their monolingual peers on a range of executive measures (Nicolay & Poncelet, 2013, for a longitudinal replication, Nicolay & Poncelet, 2015). In line with this gradient, within a group of children attending the same bilingual immersion school, a reduction in interference cost was related to balanced proficiency and length of time the child had been enrolled in the school (Bialystok & Barac, 2012). In sum, according to previous evidence, one might expect emergent bilinguals immersed in an L2 at school to show a relative benefit in WM if i) the task taps into central executive processes and ii) they have been immersed for a minimum duration.

In addition, based on the discussion regarding possible linguistic costs of bilingualism, and the involvement of domain-specific verbal resources in some WM tasks, it is possible that bilingual advantages only emerge if the WM task has relatively low linguistic demands. However, while there is some research extending the patterns of results regarding executive function from early bilinguals to L2 immersion students, there is less evidence as to whether the typical linguistic costs might also extend to this type of bilingualism, in particular, whether any consequences emerge for children's dominant L1. Research with adult sequential bilinguals showing slowed lexical access in the L1 as a consequence of L2 immersion suggests this might be the case (Linck et al., 2009). On the other hand, even with fulltime immersion programs, L2 immersion students typically return to a dominant L1 environment outside of school every day. Overall, it is currently unclear whether linguistic costs for the L1 can be observed in emergent bilingual children in L2 immersion schooling, and whether these costs might extend to verbal WM.

The present research

The main aim of the present research was to explore the development of WM in school aged children attending bilingual immersion versus monolingual schools in an otherwise monolingual community. Children were tested on two measures of verbal WM in their L1, an n-back task with letters, and reading span. Both combine executive and linguistic demands, but differ in the relative degree to which they rely on these sub-processes. Generally speaking, the executive load of the n-back task is higher, especially in regards to updating (i.e., continually monitoring and refreshing items held in WM) and interference control (i.e., managing interference from items that are currently irrelevant, but had been relevant in a preceding trial and may become relevant again). The reading span task places higher demands on linguistic processes, and is affected by factors such as verbal processing speed (Bayliss et al., 2003). In terms of different WM components, reading span is a balanced measure of the domain-general executive central and domain-general verbal storage, while the n-back task mainly reflects central executive processes (Bayliss et al., 2003, Schmiedek et al., 2009). Importantly, these differences are relative: the n-back task also involves processing and storage of verbal information, and the reading span task requires updating and interference control, but to a lesser degree than the respective other task. Our aim in selecting these two tasks was thus to identify and dissociate executive (beneficial) and linguistic (detrimental) consequences of emerging bilingualism for WM performance. Given that it is currently unknown whether the linguistic deficits found in early, balanced bilinguals (e.g. Bialystok, 2001) extend to L1 performance in immersion students, we additionally included two language tasks to measure vocabulary and lexical access. Our predictions were as follows. If L2 immersion students experience the same pattern of linguistic costs and executive benefits that has been reported for early, balanced bilinguals, we would expect monolingual children to score higher than their bilingual peers on measures of vocabulary and lexical access. We might further expect emergent bilinguals to show superior performance on the n-back task, an indicator of executive updating, while reading span, which has higher linguistic demands than the n-back task, might not show any between-group discrepancies, because an advantage in executive control might be cancelled out by linguistic processing costs.

Children were attending grade 2, 3, 5 or 8 at the time of testing. These age groups represent critical stages in the developmental trajectory of WM as well as the cumulative experience with bilingualism. Critical developmental stages are achieved with a qualitative shift around the age of seven to eight (grades 2-3) when children start to spontaneously engage in phonological rehearsal (e.g., Gaillard, Barrouillet, Jarrold & Camos, 2011), and with the beginning of adolescence (around age 11, grade 5), as the components of WM and their coordination begin to function an adult-like fashion (e.g., Gathercole et al., 2004). Further quantitative increases continue until later in adolescence. In addition, children in the second grade have been immersed in their L2 for a year and a half, the duration for which cognitive consequences started to become detectable in previous research (Poarch & van

Hell, 2012). We expected both age-related and immersion-related changes in WM performance to be more pronounced in younger children, and therefore included consecutive age groups in the lower grades and fewer selected groups of older children.

Method

Participants

Participants were 152 children (70 boys and 82 girls) who were recruited as part of a large scale research project cognition and education. At the time of testing, 38 children were attending the second grade, 42 the third grade, 42 the fifth grade and 30 the eighth grade. All participants were native speakers of Spanish, the language of testing; half of them (n = 76) were attending a fulltime English immersion program (bilinguals), the other half (n = 76) a monolingual Spanish school (monolinguals). There were equal numbers of bilingual and monolingual children within each grade level. Monolingual and bilingual children were matched for age and gender. Students with dyslexia, ADHD or other developmental disorders, and children who had been exposed to a language other than Spanish outside of school were excluded from the sample.

Bilinguals had been immersed in the English language since the beginning of first grade. For this group, all school activities and instructions were in English, except for Spanish language and literature classes, which were taught in Spanish. In the first and second grade, children had 27.5 hours of L2 immersion per week. Third and fourth graders had 26.5 weekly hours of L2 immersion, and in grades 5 through 8, children had 22.5 hours of L2 English immersion. In addition, all children (bilinguals and monolinguals) started foreign language classes in French in grade 5, with 3 hours per week. Classroom instruction and communication in the monolingual program was entirely in Spanish, with the exception of foreign language instruction in English (up until grade 4: 2h/week, starting from grade 5:

3 hours/week) and French. The two groups were compared on a number of background measures (see Table 1 for descriptive statistics).

Table 1

Socioeconomic status and fluid intelligence

	Maternal Education		Paternal Education		Home Literacy Environment		Fluid Intelligence	
Grade	**Bilinguals**	**Monolinguals**	**Bilinguals**	**Monolinguals**	**Bilinguals**	**Monolinguals**	**Bilinguals**	**Monolinguals**
2nd	5	5	5	5	2.11 (0.03)	2.05 (0.04)	24.42 (0.94)	24.16 (1.20)
3rd	5	5	5	5	2.28 (0.04)	2.02 (0.03)	26.96 (1.04)	26.38 (0.78)
5th	5	5	5	4	2.20 (0.03)	2.27 (0.03)	34.41 (0.84)	32.90 (3.03)
8th	5	5	5	5	2.08 (0.04)	2.02 (0.03)	39.53 (0.68)	35.00 (0.51)
TOTAL	**5**	**5**	**5**	**5**	**2.18 (0.05)**	**2.09 (0.03)**	**30.86 (0.80)**	**29.33 (1.03)**

Note. Socioeconomic status and general cognitive level of monolingual as compared to bilingual children by age. Group medians for maternal and paternal education are based on a 5-point scale with (5) - College +, (4) - Vocational Training, (3) - High School, (2) - Secondary/Middle School, (1) - Elementary School level degree. Values for home literacy environment express group means for the frequency of literacy-related activities at home, with (0) - Never, (1) - Sometimes, (3) - Almost always, (4) - Always. Parenthesized values represent the respective standard errors of the mean.

As an index of SES, we obtained questionnaire scores for parents' educational level. A parent's score reflects their highest diploma obtained, distinguishing between graduates of university level (5), vocational training (4), high school (3), secondary/middle school (2) and elementary school (1) institutions. Separate values were obtained for paternal and maternal education and were submitted to χ^2- likelihood ratio tests. In addition, we assessed parental investment in home literacy environment (HLE). Questions regarding HLE were included in a family questionnaire (e. g.: "We encourage our child to read."), and four answer categories were provided for each item: Never (0), sometimes (1), almost always

(2), and always (3). Sum scores were subjected to two-way factorial ANOVAs with the factors age and language status. Fluid intelligence was measured by means of the K-BIT matrices subscale (Kaufman & Kaufman, 2000), a paper and pencil test of fluid and crystallized intelligence. We used raw scores to compare performance.

The overall level of socioeconomic status and home literacy environment was high in both groups. χ^2-likelihood ratio tests revealed no monolingual-versus-bilingual differences regarding paternal or maternal education, indicating similar SES across the families of bilingual and monolingual children (maternal education level across age groups; χ^2 (4) = 1.83, p > .05, grade 2: χ^2 (4) = 2.1, p > .05, grade 3: χ^2 (4) = 5.01, p > .05, grade 5: χ^2 (4) = 2.36, p > .05, and grade 8: χ^2 (4) = 2.43, p > .05; paternal education level across age groups: χ^2 (4) = 6.59, grade 2: χ^2 (4) = 1.72, p > .05, grade 3: χ^2 (4) = 6.17, p > .05, grade 5: χ^2 (4) = 0.83, p > .05, and grade 8: χ^2 (4) = 6.44, p > .05). The ANOVA on HLE scores revealed no significant differences in function of language status, F (1, 144) = 1.71, p > .05, η_p^2 =.03, or age, F (3, 144) = 1.79, p > .05, η_p^2 =.01, and no interaction, F (3, 144) = 1.08, p > .05, η_p^2 =.02. For fluid intelligence, the effect of age was significant, F (3, 144) = 31.83, p < .001, η_p^2 =.40, but the effect of language status, F (1, 144) = 2.73, p > .05, η_p^2 =.02, and the interaction, F (3, 144) = 0.77, p > .05, η_p^2 =.02, were not.[5]

[5]Although there were no differences between bilingual and monolingual children in any of the control variables, we additionally compared the two groups within each age group. Overall there were no differences due to language status in these control variables in most comparisons (ps > .05) except for fluid intelligence in the oldest age group F (1, 28) = 28.44, p < .001, η_p^2 =.50, and for HLE in the second age group, F (1, 40) = 4.66, p = .04, η_p^2 =.10. To ensure these differences did not influence the results, we performed parallel ANCOVAs with HLE and fluid intelligence as covariates for all analyses on N-back, Reading span, Vocabulary, and RAN scores; the outcome in regards to all data patterns was the same as for the ANOVAs reported in the upcoming results section.

Procedure

Participants were tested individually in a quiet room of their school. The tasks were presented in a fixed order (K-BIT subscales, rapid automatic naming, n-back, reading span) over two separate experimental sessions, each one lasting 45 minutes. All computerized tasks were presented using E-Prime 2.0 software (Schneider, Eschman & Zuccolotto, 2002), except for the rapid automatic naming task, which was run using DMDX (Forster & Forster, 2003). Instructions read by a female native speaker of Spanish were recorded and presented over headphones at test. The instructions were repeated until the experimenter was able to confirm that the children had understood the task. Questionnaires regarding socioeconomic status, HLE and home language use were distributed at test for the children to have a parent or primary caregiver fill them out at home, and were recollected during the following test session. Teacher questionnaires including information regarding age, grade level, history of learning disorders, or other relevant diagnoses were completed by the class teachers during school breaks. Informed consent was obtained from parents or legal guardians prior to testing.

Experimental tasks and variables

Vocabulary

Expressive vocabulary knowledge was measured using the vocabulary subtest of the K-BIT (Kaufman & Kaufman, 2000). We used raw scores to assess performance.

Rapid automatic naming

The Rapid Automatic Naming (RAN) task served as an approximation to verbal processing speed. In this task, participants are required to name six recurring letters and objects that are arranged in a random order as fast as possible. Serial naming reflects lexical retrieval and phonological lexical access (Wolf, 1986) and is less related to vocabulary knowledge than discreet naming, because only a very limited number of items per category (e. g., objects) are tested.

Reading Span

The Reading Span task was based on a Spanish version of Daneman and Carpenter's task (1980) that was adapted for children (García-Madruga et al., 2013). Participants are presented with a set of simple sentences and, upon completion of a set, are asked to recall the last word of all sentences. Sentence length was restricted to 8-9 words. The number of sentences presented within a set increased over consecutive blocks, starting from two and going up to six. Instructions were followed by a practice block. Correct and incorrect answers were recorded by the experimenter on an answer sheet. The final word of a set was to never be recalled first. The procedure yields a reading span score between 2 and 6.

N-back

We used the same version of the n-back task as described by Pelegrina and colleagues (2015). The task consisted of four blocks, 0-back, 1-back, 2,-back and 3-back (the 0-back block served for practice purposes only), and items to be updated were letters. Each level of the task (0-back, 1-back, etc.) was preceded by instructions, an example consisting of six trials, and a practice block. Practice blocks were repeated until a child reached a correct percentage of 60%, and if on any task level this percentage was not reached, the procedure was ended. We calculated the sum of correct answers for each block (children who had not reached the cutoff level on a given block, and had therefore not proceeded any further on the task, received no points for the omitted blocks).

Table 2

Working memory and linguistic development

	Bilinguals	Monolinguals	Bilinguals	Monolinguals	Bilinguals	Monolinguals
Grade	**1-back**		**2-back**		**3-back**	
2nd	30.21 (1.36)	26.11 (1.68)	25.16 (1.26)	17.53 (2.89)	14.53 (3.08)	9.95 (2.91)
3rd	30.48 (1.64)	26.29 (1.49)	24.71 (2.15)	16.29 (1.85)	16.29 (2.51)	6.71 (2.13)
5th	30.43 (1.42)	33.29 (1.22)	25.86 (1.85)	17.86 (1.90)	17.86 (3.13)	17.57 (3.28)
8th	36.00 (0.60)	35.67 (0.84)	32.93 (1.05)	29.07 (2.54)	29.07 (1.18)	25.53 (2.87)
TOTAL	**31.49 (0.73)**	**30.03 (0.83)**	**26.76 (0.93)**	**23.33 (1.28)**	**18.80 (1.47)**	**14.24 (1.61)**
Grade	**Reading Span**		**Vocabulary**		**Rapid Automatic Naming**	
2nd	2.72 (0.12)	2.88 (0.12)	40.05 (1.49)	41.16 (1.10)	32.80 (1.08)	31.78 (1.39)
3rd	2.83 (0.17)	3.35 (0.21)	45.67 (1.12)	45.05 (1.05)	29.28 (1.47)	25.30 (1.13)
5th	3.69 (0.16)	3.32 (0.14)	52.54 (2.70)	51.96 (1.47)	25.27 (0.96)	23.48 (0.79)
8th	3.93 (0.28)	3.66 (0.18)	61.47 (1.33)	56.40 (1.15)	20.91 (0.62)	20.46 (0.55)
TOTAL	**3.26 (0.11)**	**3.29 (0.09)**	**49.28 (1.26)**	**48.22 (0.89)**	**27.40 (0.93)**	**25.46 (0.74)**

Note. Mean scores and standard errors (parenthesized) for working memory (1-, 2-, and 3-back scores and Reading span) and linguistic tasks (vocabulary and rapid automatic naming) in monolingual compared to bilingual children.

Results

All statistical analyses reported were two-tailed, and alpha set to .05.

Language-based development

Language-based development was assessed in terms of vocabulary and rapid naming. To measure vocabulary, we considered raw scores. For the RAN score, overall RTs from the object and letter categories were averaged to obtain a combined score. We carried out two separate ANOVAs with the factors age and language status. Unsurprisingly, the main effect of age was significant for both vocabulary, F (3, 144) = 46.78, p <.001, η_p^2 = .49, and rapid naming, F (3, 144) = 36.42, p <.001, η_p^2 =.43. For vocabulary, there were no significant bilingual-versus-monolingual differences, F (1, 144) = 1.32, $p > .05$, $\eta_p^2 < .01$, but monolinguals were significantly faster than bilinguals in rapid naming, F (1, 144) = 5.32, $p < .05$, $\eta_p^2 = .04$. The interaction between age and language status was not significant for either vocabulary, F (3, 144) = 1.20, $p > .05$, $\eta_p^2 = .02$, or RAN, F (3, 144) = 1.0, $p >.05$, $\eta_p^2 = .02$. There were significant linear trends for the effect of age on both variables, vocabulary, F (1, 64) = 197.08, $p < .001$, $\eta_p^2 = .76$, and RAN, F (1, 64) = 120.33, $p < .001$, $\eta_p^2 = .65$. Figure 1 illustrates language-based development over age.

Given that the developmental course of the linguistic abilities underlying rapid naming appeared to differ between monolingual and bilingual children, we carried out planned contrasts for consecutive age levels within each group. Effects of age were significant for both bilinguals, F (3, 72) = 18.27, $p < .001$, η_p^2=.43, and monolinguals, F (3, 72) = 19.23, $p < .001$, η_p^2=.45. Bilinguals' performance increased only marginally between the 2nd and 3rd grade, F (1, 38) = 3.57, p = .07, η_p^2=.09, whereas monolinguals showed a large, significant increase, F (1, 38) = 13.35, p = .001, η_p^2=.26. On the other hand, bilinguals' performance showed a significant increase between grades 3 and 5, F (1, 40) = 5.2, p = .03, η_p^2=.12, but monolinguals' performance did not, F (1, 40) = 1.75, $p >.05$, η_p^2=.04. Both groups improved significantly between grades 5 and 8, Fs (1, 34) ≥ 8.3, $p \leq .007$, $\eta_p^2 \geq .20$. The difference between bilinguals and monolinguals reached significance in grade 3, F (1, 40) = 4.60, p =.04, η_p^2=.10 (all other Fs ≤ 2.06, ps > .05).

Language-based development

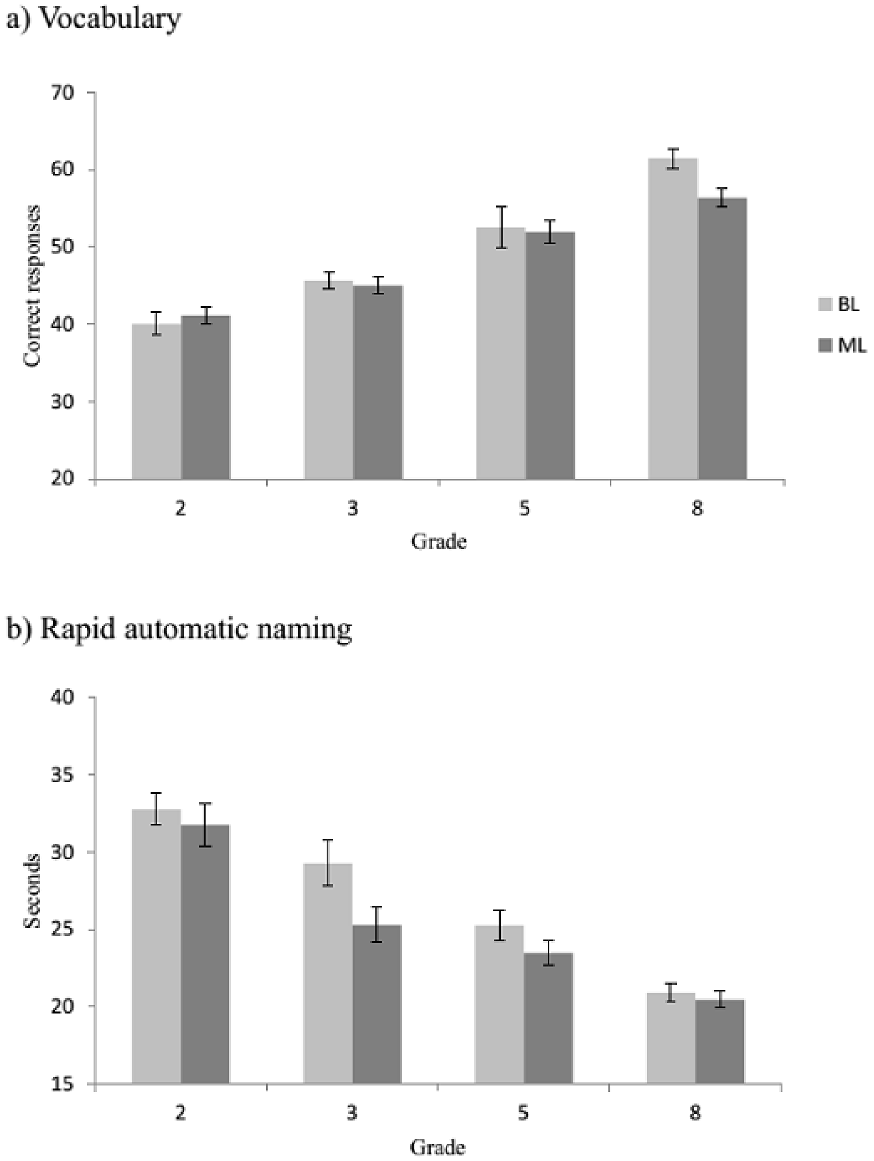


Figure 1. (a) Mean vocabulary expressed as raw scores and (b) rapid automatic naming (RAN) in seconds, for monolingual (ML) versus bilingual (BL) children divided by age. Error bars represent the standard error of the mean.

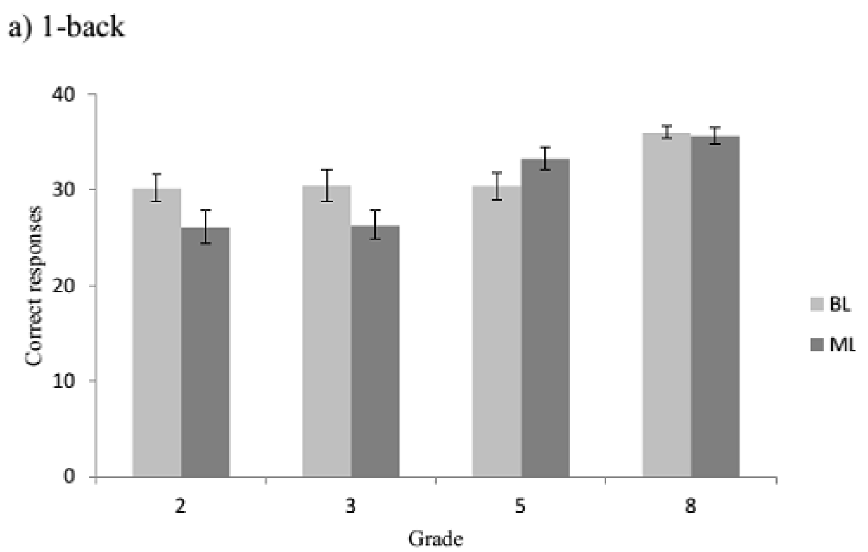
Working Memory

Two separate ANOVAs with the factors age and language status were conducted, with scores for correctly recalled items on the n-back by block and reading span scores as dependent variables. For the n-back task, block was included as an additional variable. For age-related changes in WM performance, see Figures 2 (n-back) and 3 (reading span).

N-back

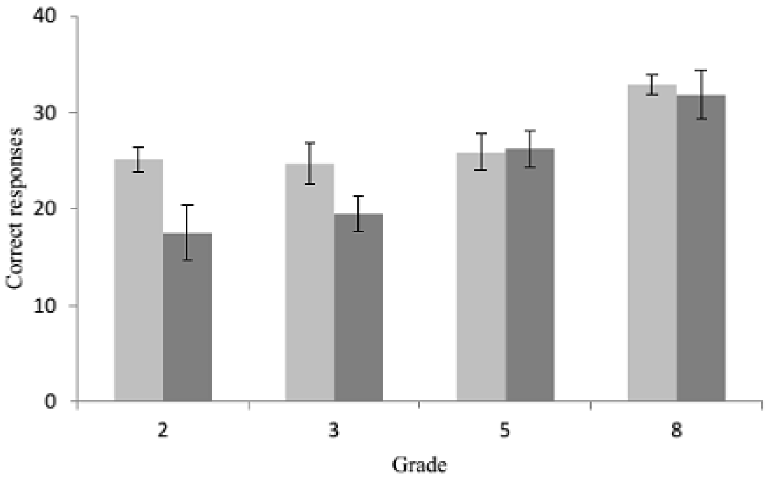
The main effect of block, F^6 (1.64, 236.39) = 181.71, p < .001, $\eta_p{}^2$=.56, and its interaction with age, F (4.93, 236.39) = 2.98, p = .01, $\eta_p{}^2$=.06, were significant, indicating stronger age effects as the task increased in difficulty (see figure 2, ps < .001, for all linear trends). However, block did not interact with any other variable (Fs ≤ .2.22, ps > .05, η_ps² ≤ .02). We further observed main effects of age, F (3, 144) = 15.32, p < .001, $\eta_p{}^2$=.24, with older children outperforming younger ones as confirmed by a linear trend, F (1, 64) = 38.87, p <.001, $\eta_p{}^2$ = .38, and language status, F (1, 144) = 5.85, p = .02, $\eta_p{}^2$=.04, with bilinguals outperforming monolinguals.

N-back



[6]Degrees of freedom for within-subject effects were corrected using the Greenhouse-Geisser correction.

b) 2-back



a) 3-back

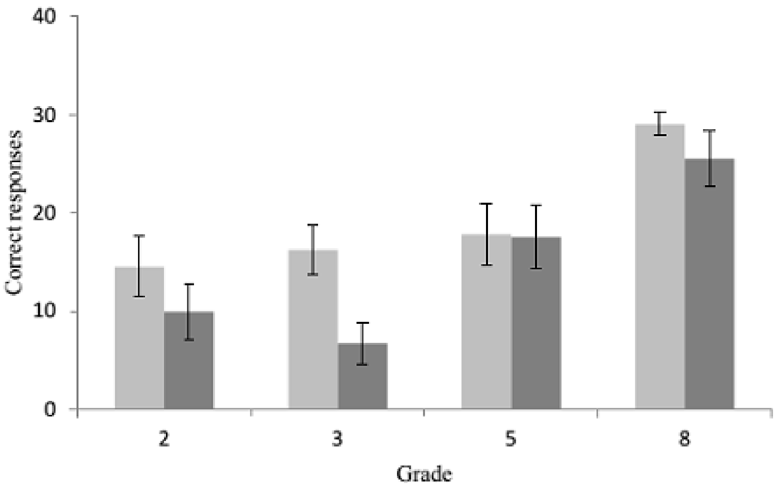


Figure 2. N-back scores (overall sum of correct responses) for monolingual (ML) versus bilingual (BL) children, divided by age for a) the 1-back, b) the 2-back, and c) the 3-back block. Error bars represent the standard error of the mean.

Although the interaction between age and language status was not significant, F (3,144) = 1.92, p > .05, η_p^2=.04, additional analyses and visual inspection of the group means suggested that the effect of language status was age-dependent[7]. To better understand these developmental patterns, we conducted a series of follow-up ANOVAs by language status and age. Given that block did not interact with language status or its interactions, for the sake of simplicity, n-back scores were collapsed across block for these analyses.

Effects of age on n-back scores were significant for both bilingual, F (3, 72) = 5.49, p = .002, η_p^2=.19, and monolingual children, F (3, 72) = 11.31, p < .001, η_p^2=.32. According to planned contrasts for consecutive age levels, bilinguals' performance increased significantly from the 5th to the 8th grade, F (1, 34) = 11.24, p = .002, η_p^2=.25. Monolinguals showed a significant increase between grades 3 and 5, F (1, 40) = 12.73, p = .001, η_p^2 =.24, and a marginally significant increase between grades 5 and 8, F (1, 34) = 3.97, p = .05, η_p^2=.11. None of the other contrasts were significant, all Fs ≤ 0.11, ps > .05, η_p^2s <.01. Separate ANOVAs by age revealed that the effect of language status was marginally significant in grade 2, F (1, 36) =3.87, p = .06, η_p^2=.10, and significant in grade 3, F (1, 40) = 6.92, p = .01, but not in grade 5 or 8, Fs ≤ 0.64, p > .05, η_p^2 ≤ .02. That is, a bilingual advantage was observed before, but not after monolinguals showed a developmental leap in task performance.

Reading Span

Reading span scores (see task description) were also subject to a significant effect of age, F (3, 144) = 11.94, p < .001, η_p^2 =.20, with older children performing better than younger ones, as indicated by a significant linear trend, F (1, 64) = 32.03, p <.001, η_p^2 = .33.

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[7]ANOVAs for combined age groups (younger children in grades 2 and 3 vs. older children in grades 5 and 8) confirm main effects of age, F (1, 148) = 30.21, p < .001, ηp^2=.17, and language status, F (1, 148) = 4.75, p = .03, ηp^2=.03, as well as a significant interaction, F (1, 148) = 4.42, p = .03, ηp^2=.03. Comparing the effect of language status within the two broader age groups revealed that younger bilingual children, F (1, 78) = 9.72, p < .01, ηp^2=.11, but not in older ones, F (1, 78) = .003, p > .05, ηp^2 <.05, outperformed monolinguals on the n-back task.

Bilinguals and monolinguals performed at the same overall level, F (1, 144) = .01, $p > .05$, $\eta_p^2 <.01$, but there was a significant interaction between age and language status, F (3, 144) = 2.92, $p = .04$, $\eta_p^2 =.06$[8].

Reading span

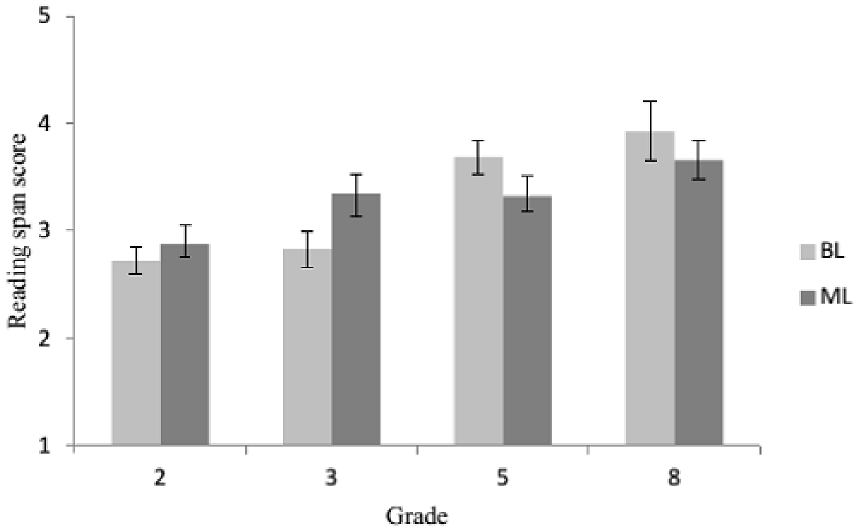

Figure 3. Mean reading span for monolingual (ML) versus Bilingual (BL) children, divided by age. Error bars represent the standard error of the mean.

Follow-up ANOVAs by language status showed significant age effects for bilinguals, F (1, 72) = 11.06, $p < .001$, η_p^2=.32, and monolinguals, F (1, 72) = 3.34, $p = .02$, η_p^2=.12. The developmental course for this task differed for both groups as in monolinguals, a marginally significant improvement was observed between grades 2 and 3, F (1, 38) = 3.59, $p = .07$, η_p^2=.09, while bilinguals' performance increased at a later stage, between

[8]ANOVAs with combined age groups confirmed the effect of age, F (1, 148) = 29.33, $p < .001$, η_p^2 =.17 and the significant interaction between age and language status, F (1, 148) = 7.44, $p = .007$, η_p^2 =.05. The effect of language status remained non-significant, F (1, 148) = 0.01, $p > .05$, $\eta_p^2 < .01$. Younger children had better reading span scores than their bilingual age peers, F (1, 78) = 4.48, $p = .04$, η_p^2 =.05, while in older children, there was a tendency towards a bilingual advantage, F (1, 78) = 3.08, $p = .08$, η_p^2 =.04.

grades 3 and 5, F (1, 40) = 14.26, p = .001, η_p^2=.26. None of the other planned contrasts between consecutive grade levels were significant, Fs ≤ 2.20, p > .05, η_p^2 <.06. ANOVAs by age showed marginal effects of language status in 3rd grade, F (1, 40) = 3.76, p = .06, η_p^2=.09, where monolinguals reached higher scores, and 5th grade, F (1, 40) = 3.02, p = .09, η_p^2 =.07, where bilinguals performed better. Thus, the outcome of the between-group comparison changed after bilinguals showed an age-related increase. No significant between-group differences were observed for 2nd graders, F (1, 36) = .86, p > .05, η_p^2 =.02, or 8th graders, F (1, 28) = .65, p > .05, η_p^2 =.02.

Correlations

In order to corroborate the assumption that reading span is more related to verbal processing than the n-back task, we calculated partial correlations between WM tasks and rapid naming (where bilinguals had scored lower than monolinguals) for the entire sample while controlling for the effect of age. Reading span proved to be significantly correlated with RAN scores, r = -.17, p =.04, but n-back scores did not (r = -.02, p > .05). The relationship between n-back and reading span scores did not reach significance either (r = .01, p >.05).

Discussion

The aim of this research was to explore the development of WM performance in school age and assess whether emergent bilingual children immersed in an L2 at school show developmental modulations. To that end, we compared children aged seven through 14 who were enrolled in the second, third, fifth, or eighth grade of an L2 immersion school to monolinguals of the same age on two measures of WM. Research into the cognitive consequences of L2 immersion education is still scarce, although this type of schooling has been gaining popularity. Our goal was to build on previous findings (e.g. Bialystok &

Barac, 2012, Nicolay & Poncelet, 2013) to fill this gap. Although the present study was cross-sectional as most research on bilingualism and cognitive control, we aimed to ensure that both groups be as similar as possible in factors other than language status, including age, gender, SES, fluid intelligence and home literacy environment. Main effects of age for measures of linguistic and WM performance confirm that the selected tasks are sensitive measures of individual differences in the cognitive development of children this age in the respective domains.

Our parting hypothesis was that emergent bilingualism – the onset of multiple language use and acquisition – is associated with both cognitive advantages (i.e., enhanced cognitive control) and deficits (i.e., delayed or impaired language skills), and that both are relevant for WM performance (see also Bialystok, 2009). We thus predicted that i) emergent bilinguals might lag behind their monolingual age-peers on language tasks in the L1, and that ii) emergent bilinguals would excel on a WM task that places high demands on executive control and is linguistically less demanding (n-back task). Finally, we predicted that if both linguistic costs and executive advantages occur in emerging bilinguals, the two groups might show similar performance on a WM task that places equal demands on executive and non-executive linguistic processes (i.e., reading span).

Regarding verbal processing in the L1, we found that emergent bilingual children were significantly slower than their monolingual counterparts, as evidenced by reaction times on the rapid automatic naming task. This finding stands in line with previous research showing relatively slower lexical access in bilinguals (e.g., Ivanova & Costa, 2008, Yan & Nicoladis, 2009), especially slowed L1 processing as a consequence of L2 immersion in sequential bilingualism (Linck et al., 2009). To our knowledge, this research is the first one to extend these findings to children immersed in the L2 at school. However, it should be noted that this difference was only significant for third graders, suggesting that the effect of

L2 immersion on the L1 was not persistent in our sample. With developmentally increasing cognitive control and language abilities, children likely become more efficient in managing cross-linguistic interference, often assumed to be the cause for slower lexical access in bilinguals. Thus, relatively subtle influences from the L2 (note that emerging bilinguals in this sample return to a monolingual, L1 dominant environment outside of the school context) might become more difficult to detect later in development. On the other hand, both groups showed similar levels of vocabulary knowledge, suggesting a dissociation of knowledge-based and processing-based aspects of language development. A similar pattern was observed by Yan and Nicoladis (2009), who report greater difficulties with lexical access, combined with monolingual-like vocabulary scores in school-aged (balanced) bilinguals. Within-language vocabulary scores of bilingual children depend on the exposure time to each language (Genesee & Nicoladis, 2007), while the difficulty in lexical access and retrieval can be explained as being due to the added cognitive load from the second language during bilinguals' language processing (Yan & Nicoladis, 2009).

In regards to WM updating, we observed a bilingual advantage in the younger age groups (grades 2 and 3), although no between-group differences were observed for older children (grades 5 and 8). Although our version of the n-back task uses verbal content, it is a relatively pure measure of executive WM updating. The finding for younger emergent bilinguals is thus consistent with previous research showing an executive advantage in L2 immersion students (e.g., Bialystok & Barac, 2012, Nicolay & Poncelet, 2013), as well as research with early bilinguals using WM tasks that were high in executive load (Carlson & Meltzoff, 2008, Morales et al., 2013). This finding suggests that emergent bilingualism may alter the developmental trajectories of WM-related processes, rather than ultimate achievement as such (we will come back to this point). Previous research with immersion students has often been limited to younger children within the first three years of L2 immersion (e.g., Nicolay & Poncelet, 2013, 2015, Poarch & van Hell, 2012), so it is unclear to what extent the lack of between-group differences for older immersion students is consistent or inconsistent with these studies.

Reading span requires executive control, but at the same time, it relies more heavily on linguistic processing. In line with some previous research (e.g. Blom, Küntay, Messer, Verhagen, & Leseman, 2014), we postulated that putative bilingual costs and benefits would cancel each other out, and predicted no between-group differences for this task. Memory falls onto a middle ground in terms of bilingual costs and benefits: as executive and linguistic processes both affect performance, the relative outcome compared to monolinguals depends on the extent to which a task draws on either (see Bialystok, 2009). Our results indicate the greatest age-related outcome differences for this task. In particular, younger bilinguals (grade 3) who outperformed their monolingual age-peers on the n-back task, showed a marginal disadvantage on the reading span task. It seems that the linguistic deficit in bilingual children at this age level showed through on the reading span task as it requires a relatively high level of linguistic functioning. This dissociation suggests that is important to consider the specific task content, that is, the relative contribution of executive and non-executive components, to the outcome when comparing bilinguals and monolinguals on WM paradigms. A recent study suggests that linguistic deficits can affect bilinguals' performance on WM negatively on tasks tapping both central executive and domain-general verbal components, although contrary to our research, verbal WM was tested in bilinguals' less dominant L2 (Blom et al., 2014).

As mentioned above, it is important to note that between-group differences emerged at certain grade levels. While the interaction with age was only significant for reading span, further comparisons revealed that the language effects for the n-back task and rapid automatic naming were also clearly driven by differences in younger age groups. Thus, our data suggest that L2 immersion may boost or delay WM processes at earlier developmental stages, but all children eventually reach a similar level of performance (see Morales et al., 2013, for a similar interpretation). A comparison of age effects within-group confirmed that immersion students in grades 2 and 3 performed the n-back task at a level that monolinguals did not reach until the 5th grade. The pattern for the reading span task was reversed, as monolinguals showed increased performance between grades 2 and 3 and bilinguals lagged behind until later on (grade 5). Similarly, monolinguals' naming performance showed a large and reliable improvement between grades 2 and 3, while the age-related reduction in bilinguals was significant later on, between grades 3 and 5. Together, data from these two tasks suggest that linguistic processing abilities develop earlier in monolinguals whereas they develop more progressively in emergent bilinguals. Both groups also showed increased performance in rapid naming between the 5th and 8th grade, suggesting that speed and fluency of lexical access continue to increase substantially into adolescence but at this stage, development in monolingual children and immersion students proceeds similarly. Again, this suggests that rather than affecting ultimate attainment, becoming immersed in a second language can alter the developmental course of language-based abilities. The lack of between-group differences in the higher grades may be surprising, as one might expect that with longer exposure to a bilingual immersion environment, cognitive consequences in terms of measurable effects should increase. On the other hand, it is plausible that younger bilinguals who are still new to interacting in their less dominant L2 experience the largest transfer effects, as cross-language interference and executive control demands should be particularly high at this stage. Cognitive consequences of bilingualism tend to be most easily detectable in developmental stages of less-than-optimal executive performance, that is, childhood and old age (Craik & Bialystok, 2006) and training effects in the context of executive function generally tend to be larger at earlier intervention and developmental stages (Diamond & Lee, 2011). Finally, it should be noted that unexpected between-group differences were observed in the oldest age group in terms of fluid intelligence and also to a lesser extent, in terms of vocabulary, as suggested by descriptive values. It is possible that these disparities might reflect cognitive consequences of bilingualism that take more time to emerge (note the greater age gap between the two older groups): fluid intelligence is closely related to cognitive control (Conway, Kane & Engle, 2003), and bilingual adults tend to show an advantage in learning new words, which could contribute to an emerging advantage in vocabulary (e.g. Kaushanskaya & Marian, 2009). However, these effects were not anticipated in our hypotheses, and they do not appear to be in any relation with the earlier effects observed for verbal working memory that were the focus of this work.

Conclusion

In conclusion, the present research offers several contributions to understanding WM development and bilingualism. We report one of the first studies to investigate the cognitive consequences of emergent bilingualism through L2 immersion at school and extend some of the findings from early bilinguals to this group. In regards to the nature of WM development, our data suggest that WM is more susceptible to modulatory effects at earlier stages. Thirdly, we show that WM tasks that differ in the relative contribution of sub-components may lead to different outcomes of a between-group comparison. WM is a multi-component construct (e.g., Baddeley & Hitch, 1974, Gathercole et al., 2004,), and our findings highlight the importance of considering the specific task content, and ideally, to use several alternative tasks that allow one to estimate differences at the level of sub-components. The important question remains whether the specific modulations have practical consequences. Further study is needed in order to determine whether any of these effects show transfer into other cognitive abilities and domains. This should prove a fruitful field for future research.

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Experiment 2. Reading comprehension and Immersion schooling: Evidence from component skills[9]

The present research aims to assess literacy acquisition in children becoming bilingual via second language immersion in school. We adopt a cognitive components approach, assessing text-level reading comprehension, a complex literacy skill, as well as underlying cognitive and linguistic components in 144 children aged 7 to 14 (72 immersion bilinguals, 72 controls). Using principal component analysis, a nuanced pattern of results was observed: although emergent bilinguals lag behind their monolingual counterparts on measures of linguistic processing, they showed enhanced performance on a memory and reasoning component. For reading comprehension, no between-group differences were evident, suggesting that selective benefits compensate costs at the level of underlying cognitive components. Overall, the results seem to indicate that literacy skills may be modulated by emerging bilingualism even when no between-group differences are evident at the level of complex skill, and the detection of such differences may depend on the focus and selectivity of the task battery used.

[9] This experiment h as Hansen, L. B., Morales, J., Macizo, P., Duñabeitia, J. A., Saldaña, D., Carreiras, M., Fuentes, L. J., & Bajo, M. T. (in press). Reading comprehension and immersion schooling: Evidence from component skills. *Developmental Science.*

Bilingual immersion education refers to a pedagogical concept where curricular content is taught in a language other than the students' native or home language. The language of schooling is typically a minority language within the community or societal context, and the goal is for children undergoing immersion to achieve maximum - ideally native-like - proficiency in the target language (Wright, 2013). While the motivations for immersion schooling are multifaceted (among the most important, enhancing career prospects, protecting cultural heritage, promoting multicultural integration) and tend to be differentially weighted across countries (Johnson & Swain, 1997), bilingual immersion programs are growing in popularity and numbers everywhere around the globe. In light of this ongoing trend, questions regarding the academic, linguistic and cognitive effects are highly topical. Systematic research is still sparse, although researchers have long expressed the need to systematically evaluate the linguistic and academic outcomes of immersion schooling and have started to do so as early as the 1970s. Most of this research comes from Canada, where there has been a long-standing tradition of French-immersion programs in Anglophone areas (Wright, 2013, but see Oller & Eilers, 2002). Therefore, the relevant body of data is almost entirely limited to the Canadian school system, immigration system and society as a whole, as well as L1 English-L2 French as a specific language combination. The present study centers on reading comprehension in school-aged native speakers of Spanish in English immersion schooling, a sample pertaining to a rapidly growing but thus far understudied population.

An important issue of concern regarding L2 immersion education has been whether it is associated with any adverse consequences for the development of the native, majority language. Concerns have been raised by researchers from the educational and the cognitive field. From a pedagogical-educational viewpoint, the key issue is whether curricular objectives for language and literacy are achieved at a pace comparable to the monolingual norm. In bilingual immersion schooling, most classroom interaction, including explicit instruction in literacy skills, is limited to the L2. It is thus possible that the acquisition of higher order L1 language and literacy skills might be delayed relative to the standard, monolingual schooling in the L1.

From the cognitive perspective, performance on the higher order language skills that are explicitly taught relies on a number of underlying cognitive and linguistic skills and processes that are still developing. Phonological and orthographic ability, morphological knowledge, as well as vocabulary and syntax comprehension are critical for both lexical reading skill and supralexical reading comprehension, whereas the latter additionally relies on verbal memory capacity, reasoning and inference processes (Bowers, Kirby & Deacon, 2010, Cain, 2007, Cutting & Scarborough, 2006, Oakhill, Cain & Bryant, 2003, Perfetti, Marron, & Foltz, 1996). Reading speed is another factor that has been discussed as a basic component of reading comprehension (Adlof, Catts & Little, 2006, Cutting & Scarborough, 2006, Joshi & Aaron, 2000). The contribution of component processes may differ with grade level (Diakidoy, Stylianou, Karefillidou & Papageorgiou, 2005, Tilstra, McMaster, Van den Broek, Kendeou & Rapp, 2009), across languages and writing systems (Saiegh-Haddad & Geva, 2008, Ziegler et al., 2010), as well as bilingual status (monolingual vs. bilingual children of different language pairs, Marinova-Todd, Siegel & Mazabel, 2013), and there may be complex interactions between these factors. For example, the strength of the relationship between morphological awareness and reading in English appears to depend on whether children know an additional language (in this case always as the L1), and the degree of morphological transparency of that language (Marinova-Todd et al., 2013).

In addition, accumulated data from cognitive linguistics research over the last two decades show that bilingual and monolingual minds often function differently even when overt performance is comparable. Full immersion students, even those from a monolingual background, usually reach functional, and in some aspects native-like, proficiency in a second language (Harley, Allen, Cummins & Swain, 1991) and are therefore best characterized as *emergent* bilinguals. For earlier, more balanced bilinguals, selective advantages and drawbacks in linguistic and nonlinguistic domains have been observed (Bialystok, 2001, 2010), and there is some evidence to suggest that pertinent findings may extend to L2 immersion students (Bialystok, Peets, & Moreno, 2014). These observations are important from a cognitive components perspective, as they suggest there may be at least two ways in which bilingual immersion schooling might affect the acquisition of reading comprehension and literacy: directly, through (limited) exposure and instruction in L1 curricular content, or indirectly, by virtue of processing differences at the level of component skills that result from the emergent bilingual status.

As far as educational research into L1 literacy skills goes, some deficits have in fact been observed in English-French immersion students compared to monolingual age peers. More specifically, children undergoing full L2 immersion tend to show a temporary delay in L1 literacy skills including letter-sound conversion, spelling, as well as lexical and higher-level reading abilities (Barik & Swain, 1975, 1976a, 1976b, Genesee & Stanley, 1976, Harley, Hart & Lapkin, 1986, Kendall, Lajeunesse, Chmilar & Shapson, 1987, Lambert & Tucker, 1972, Lapkin & Swain, 1984, Swain & Lapkin, 1982, Turnbull, Hart & Lapkin, 2003, for reviews, see Bournot-Trites & Tellowitz, 2002, Genesee & Jared, 2008). These early studies followed several cohorts longitudinally and consistently replicated an initial delay, which later disappears (and sometimes reverts) after several years of schooling and introduction of the L1 as a supplementary medium of instruction. The most persistent delay is observed for spelling, while oral skills appear to be less affected (Barik & Swain, 1975, 1976a, 1976b, Lambert & Tucker, 1972). This pattern is plausible in light of the fact that the acquisition of written language relies on formal instruction much more than oral language. Notably, past research shows that the linguistic deficits in bilinguals are relatively minor and largely temporary despite the lack or limitation of explicit instruction, which suggests that literacy skills may transfer from L2 to L1. Research suggests that such transfer is, in principle, possible, but might depend on the language pair (Ramirez, Chen, Geva, & Kiefer, 2010).

Evidence from early, more balanced bilinguals, on the other hand, often shows a characteristic pattern of cognitive and linguistic abilities in bilingual relative to monolingual children: while the acquisition of formal knowledge of language, like vocabulary and grammar, may be delayed, metalinguistic skills like morphological, syntactic, phonological or word awareness tend to be temporarily (in the case of phonological awareness) or persistently (in the case of morphological awareness) enhanced (for reviews, see Bialystok, 2002, 2005, 2007, 2010). Another persistent finding is relatively slower lexical access in bilinguals across lifespan development (e.g., Ivanova & Costa, 2008, Michael & Gollan, 2005, Yan & Nicoladis, 2009).

Research investigating whether, and under which conditions, these findings also apply to L2 immersion students is very limited. One study confirmed an advantage for morphological awareness, combined with a temporal delay for verbal fluency using a letter fluency task in L2 immersion students compared to monolinguals (Bialystok, Peets, & Moreno, 2014). Tingley and colleagues (2004) observed no differences between children attending L1 monolingual vs L2 immersion programs regarding phonological awareness in the early school years, but, consistent with the earlier literature, showed a disadvantage for immersed children in word recognition at this age. In addition, a few studies compared the development of L1 versus L2 linguistic and metalinguistic skills, including vocabulary, lexical access, phonological and morphological awareness *within* samples of L2 immersion students (e.g., Comier & Kelson, 2000, Hermanto, Moreno & Bialystok, 2012, Joy, 2011). Data from these studies suggest that in L2 immersion schooling, L1 skills tend to evolve at a slower pace than L2 skills (Joy, 2011) and the acquisition of formal linguistic knowledge is delayed relative to metalinguistic development (Hermanto et al., 2012). However, these studies did not implement a monolingual control group and thus do not allow one to compare performance across different school types. All of these studies were based on L1-English children immersed into L2-French at school.

The sum of between-group differences in formal linguistic knowledge and language processing might render bilingual language processing relatively more effortful than is the case for monolinguals. Arguably, this might carry over to the level of complex skill and academic outcomes observed on the surface. At present, research into the cognitive consequences of bilingual immersion schooling at the level of cognitive processes is still at its beginning stages. To our awareness, there is no systematic research linking these patterns of monolingual vs. bilingual costs and benefits to a complex literacy skill like reading comprehension. In addition, early evaluations of reading ability in immersion students (e.g., Barik & Swain, 1975, 1976a, 1976b) did not tend to distinguish reading comprehension at the text level from reading skill at the sentence or word level, and often did not test inference-skills. The present article seeks to integrate educational and cognitive approaches. Our main focus is on text-level reading comprehension, a complex cognitive skill that is taught as part of school curricula and is crucial to general academic achievement and continuous knowledge acquisition throughout the lifespan. As discussed above, reading comprehension has been identified as a potential problem area in children undergoing L2 immersion schooling (Cummins, 1998). To gain a thorough understanding of children's performance, in addition to written text comprehension, we will assess a series of underlying and related component processes, including vocabulary knowledge, lexical access in production and comprehension, phonological and morphological abilities, verbal working memory and long-term memory, as well as sentence-level syntactic comprehension. This cognitive components approach allows us to gain theoretically and practically relevant insights: if a deficit does exist at the complex skill level, we might be able to localize the source in the form of a subjacent component factor that might present a bottleneck. If a bilingual advantage is observed, we can pinpoint the factors that bring about this advantage. Even if no overt discrepancies are observed at the level of complex skill, there might nevertheless be underlying qualitative processing differences.

In addition to extending existing research to different hierarchical levels of linguistic skill, the present study is based on a relatively unstudied language pair in this context, L1 Spanish and L2 English[10]. Nearly all of the research on immersion education discussed above was done in Canada and focuses on English as the home language and French as the medium of instruction. It is currently unclear whether the results can be generalized across school systems and language pairs. As mentioned before, successful performance on L1 literacy skills in absence of explicit instruction depends on the extent of within- and between-language transfer, which may differ across languages and language pairs. For example, a study investigating L1-Spanish L2-English children observed cross-linguistic transfer of morphological awareness to reading from Spanish to English, but not from English to Spanish (Ramirez et al., 2010). Note that Spanish, the native language of our participants, has a much more transparent orthography, with a clear grapheme-to-morpheme conversion, and more complex morphology than English, the language of instruction. As a consequence of its opacity, reading acquisition proceeds at a slower rate in English, the least transparent of the alphabetic languages, compared to more transparent languages (Bruck, Genesee, & Caravolas, 1997, Frith, Wimmer, & Landerl, 1998, Goswami, Gombert, & de Barrera, 1998; Goswami, Ziegler, Dalton, & Schneider, 2001,

[10] Although some very interesting research has been carried out with L1-Spanish speakers in the United States who were immersed in their second language, English, at school, by attending either fulltime English instruction or two-way Spanish-English immersion education (Oller & Eilers, 2002), these studies are based on different contextual conditions: with the language of schooling being the majority language, immersion students were already bilingual at school entry and mostly came from bilingual homes. Their L2 was compared to monolinguals' L1.

Seymour, Aro, & Erskine, 2003, for a review, see Ziegler & Goswami, 2005). The constellation for L1-English and French immersion is different, with French having the relatively more transparent orthography and richer morphology. Such differences might further determine the effects of immersion schooling in the specific case of L1-Spanish L2-English.

There are two nested research questions:

1. Do L1-Spanish children enrolled in an L2-English immersion program differ from their monolingual Spanish age peers in terms of L1 text-level reading comprehension?
2. Are there any between-group differences in terms of selected skills and abilities that are known to contribute to reading comprehension, including listening comprehension, vocabulary knowledge, phonological and morphological awareness, syntax, memory, rapid naming and visual word recognition?

Method

Participants

Participants were 144 children aged 7 through 14, divided into three different age groups: 50 seven to eight year olds [*M* = 7.44 (0.5), grade 2] 52 nine to ten year olds [*M* = 9.6 (0.5), grade 3 and 4], and 42 eleven to fourteen year olds [(*M* = 11.93 (0.9), grade 5 and 8][11]. All were native speakers of Spanish from monolingual homes in Granada, Spain. Seventy-two children were enrolled in an English immersion program where they had been since the first grade (emergent bilingual children, BL), the remaining 72 children had been attending a monolingual school (monolingual children, ML). Children in the immersion

[11] These age groups were selected because they correspond with important developmental stages in cognitive development, and in the trajectory of literacy acquisition. For reading comprehension in particular, individual and age- or grade related variation might differ according to developmental stage, hence the need for a finer-grained categorization in terms of age.

program received almost all schooling in English, apart from Spanish language and literature classes, and foreign language instruction in French (3h/week starting at age 10). For first and second graders (7-8 year olds), 18h per week were held in English, for third and fourth graders (9-10 year olds), 17h per week, for 5th-8th graders, 13h per week. In the monolingual program, all classes were held in L1-Spanish, with the exception of foreign language instruction in English (1st through 4th grade/7-10 year olds: 2h/week, 5th through 8th grade/11-14 year olds: 3h/week) and French (3h/week starting at age 10). Extracurricular and non-teaching hours made up 9.5h per week that were held in L2-English in the immersion program and in L1-Spanish in the monolingual program.

The sample was drawn from a large scale study on cognition and education. We identified the children from the English immersion program from the corresponding age groups that had participated in the tasks. From all monolingual programs, we first determined the one that matched the bilingual immersion program the closest on factors like socioeconomic status (SES), home literacy environment (HLE, the degree in which parents engage in, provide and/or encourage literacy-related activities in the home). Parental education level, assessed via family questionnaires served as an approximation to SES (Ensminger, Fothergill, Bornstein, & Bradley 2003). We asked for the fathers' and mothers' highest educational diploma obtained separately, distinguishing between university level (5), vocational training (4), high school (3), secondary/middle school (2) and elementary school (1). Home literacy environment was also assessed in questionnaire using items with 4 response categories (e. g.: "We encourage our child to read", response categories: 0-"never", 1-"sometimes", 2-"almost always", 3-"always").

Each bilingual child was then matched with a monolingual by randomly selecting one child from a group of monolinguals equated for age, grade level and sex. Children diagnosed with neuropsychological disorders or learning disabilities, as well as children who had been exposed to a language other than Spanish outside of school (e.g., children from bilingual families) were excluded from the sample a priori. Prior to testing, informed consent to children's participation was obtained from a parent or legal guardian.

The resulting two groups of children did not differ in maternal education level (overall: $\chi^2 LL$ (4) = 4.26, p >.10, 7-8 year olds: $\chi^2 LL$ (4) = 3.39, p >.10, 8-9 year olds: χ^2 LL (4) = 4.86, p >.10, 11-14 year olds: χ^2 LL (4) = 2.92, p >.10), paternal education level (overall: χ^2 LL (4) = 2.32, p >.10, 7-8 year olds: χ^2 LL (4) = 3.84, p >.10, 8-9 year olds: χ^2 LL (4) = 7.60, p >.10, 11-14 year olds: χ^2 LL (4) = 0.62, p >.10) or home literacy (overall: F (1, 142) = 3.04, p > .05, η_p^2=.02, 7-8 year olds: F (1, 48) = 1.54, p > .05, η_p^2=.03, 9-10 year olds: F (1, 50) = 0.97, p > .05, η_p^2=.02, 11-14 year olds: F (1, 40) = 0.57, p > .05, η_p^2=.01). See table 1 for measures of parental education and home literacy environment divided by school and age.

Table 1

Socioeconomic status

	Maternal Education		Paternal Education		Home Literacy Environment			
Age	**BL**	**ML**	**BL**	**ML**	**BL**		**ML**	
7-8	5	5	5	5	2.24	(0.08)	2.09	(0.09)
9-10	5	5	5	5	2.20	(0.10)	2.08	(0.07)
11-14	5	5	5	5	2.15	(0.11)	2.04	(0.10)
TOTAL	**5**	**5**	**5**	**5**	**2.20**	**(0.05)**	**2.07**	**(0.07)**

Note. Socioeconomic status and general cognitive level of monolingual (ML) as compared to emergent bilingual (BL) children by age. Group medians for maternal and paternal education are based on a 5-point scale with (5) - College +, (4) - Vocational Track, (3) - High School, (2) - Secondary/Middle School, (1) - Elementary School level degree. Values for home literacy environment express group means for the frequency of literacy-related activities at home, with (0) - Never, (1) - Sometimes, (2) - Almost always, (3) - Always. Parenthesized values represent the respective standard errors of the mean.

Procedure

All tasks were conducted in a school setting, in 4 sessions of 45 minutes duration each, and during regular school hours in a quiet room inside the school. Children were assessed individually. Data regarding socioeconomic status, family and language background, home literacy environment, as well as academic, psychological and neurological history were obtained in the form of questionnaires to be filled out by parents or guardians at home. Additional questionnaire data regarding academic performance and psychological or neurological conditions was collected from teachers during recess. Instructions read by a female native speaker of Spanish were presented auditorily through headphones. Instructions were repeated as many times as necessary to ensure children understood what they had to do. All instructions and task contents were presented in Spanish. Computerized tasks were presented using E-Prime 2.0 (Schneider, Eschman & Zuccolotto, 2002) or DMDX (Forster & Forster, 2003) software.

Tasks and scoring

Fluid and crystallized intelligence.

Fluid (nonverbal) and crystallized (verbal) intelligence were assessed using the Kaufman Brief Intelligence Test (K-BIT, Kaufman & Kaufman, 2004). We used the direct scores for both scales (direct scores range from 0-48 for the fluid intelligence and from 0-82 for the crystallized intelligence subscale).

Phonological awareness.

We used a phoneme deletion task, a measure of phonological awareness in school aged children (see McDougall, Hulme, Ellis & Monk, 1994). Children listened to individual words that were presented over headphones, and were asked to repeat the same word out loud omitting a certain phoneme. For example, a child might hear the word “nube” (engl.: “cloud”) and be asked to repeat the word without the “n”, in which case the correct answer would be “ube”. Participants’ responses were recorded and mean accuracy rates calculated to obtain a score per participant.

Lexical access and reading fluency.

Rapid automatic naming.

Participants are presented with an array of six recurring items (e.g., objects) in random order and are asked to name the entire sequence as fast as possible without making mistakes. Rapid naming measures phonological access, lexical retrieval, and reading fluency in production (Bowers & Swanson, 1991, Wolf, 1986, Wolf & Bowers, 1999) and is less influenced by vocabulary knowledge than discreet naming, where a much larger number of items per category is used. Participants' scores consist of naming times for the complete array in seconds, averaged across the objects and letters categories.

Lexical decision task.

In the lexical decision task, participants read Spanish words as well as strings of letters that follow the phonotactic rules of the Spanish language but do not form an existing word. Participants are instructed to press one of two buttons to indicate whether the presented letter string is a Spanish word ("yes" response) or a nonword ("no" response). The lexical decision task measures lexical access and reading fluency in comprehension. For this task, we calculated mean reaction times for words to measure the speed of lexical access.

Orthographic skill.

Children were presented with two letter strings and had to indicate by pressing a button whether they both were the same. Stimuli contained identical pairs, as well as pairs where one letter string was a word and the other one contained the same letters, but some of them in transposed position (e.g. "casino" vs. "CANISO"). For each participant, a score for the transposed-letter effect was calculated: accuracy rate for identical pairs minus accuracy rates for transposed letter pairs (see Duñabeitia, Orihuela, & Carreiras, 2014, for a similar task).

Morphological awareness.

The task was similar to the one used by Barber and Carreiras (2005). Participants were presented with sentences that were either grammatically correct (10 sentences) or contained a gender or number violation (10 sentences each). All sentences contained an adjective in predicative position following a noun, and violations are always implemented in the adjective. In Spanish, adjectives and nouns are marked for gender and number and must therefore be consistent in this type of sentence. Condition was counterbalanced across participants, and lexical frequency, number of letters, and number of syllables of target adjectives were controlled for each condition (correct, gender-inconsistent, number-inconsistent). See Table 2 for examples of the 4 different conditions. Participants were asked to indicate by pressing a button whether the present sentence was correct or not, scores were calculated as accuracy rates averaged across sentences containing gender and number violations, and corrected by error rates for correct sentences.

Table 2.

Condition	**Spanish sentence**	**English translation**
Correct	Las casas de madera son muy bonitas.	The wooden houses $_{\text{[fem. pl.]}}$ are very pretty $_{\text{[fem. pl.]}}$.
Gender violation	Las casas de madera son muy bonitos.	The wooden houses $_{\text{[fem. pl.]}}$ are very pretty $_{\text{[mas. pl.]}}$.
Number violation	Las casas de madera son muy bonita.	The wooden houses $_{\text{[fem.pl.]}}$ are very pretty $_{\text{[fem. sing.]}}$.

Note. Abbreviations in parenthesis indicate gender and number in the Spanish original, with fem. = feminine, mas. = masculine, pl. = plural, sing. = singular.

Sentence comprehension.

Sentence-level comprehension was measured by means of a picture-sentence matching task. Materials were adapted from the syntax scale of the PROLEC-R test battery for reading processes in Spanish (Cuetos, Rodríguez, Ruano, & Arribas, 2007). Sentences were presented in written form on the computer screen, alongside with 4 pictures from which children had to select the one representing the sentence. Sentence types differed in complexity: attributive and simple active structures, active sentences containing a negation, passive structures, sentences containing a focalized object, a split subject, a split object, a subject-subordinate clause or an object-subordinate clause. After assessing difficulty empirically, we averaged accuracy rates across the most difficult sentence types, namely passive sentences, sentences containing a focalized or a split object, and sentences containing an object-subordinate clause. See Table 3 for examples of each of the averaged (difficult) sentence types. This task measures the ability to interpret sentence meaning despite increased difficulty due to noncanonical order, or increased working memory load due to the need to maintain a syntagma active while reading the rest of the sentence (e.g., Montgomery, Magimairaj, & O’Malley, 2008).

Table 3.

Sentence type	**Spanish**	**English translation**
Passive	El perro es mordido por el gato.	The dog $_{\text{[subj.]}}$ is bitten by the cat $_{\text{[obj.]}}$.
Focalized object	Al perro lo muerde el gato.	The dog $_{\text{[obj.]}}$ bites the cat $_{\text{[subj.]}}$.
Split object	Es al perro al que muerde el gato.	It’s the dog $_{\text{[obj.]}}$ whom the cat $_{\text{[subj.]}}$ bites.
Object-subordinate clause	El perro al que muerde el gato es grande.	The dog $_{\text{[obj.]}}$ whom the cat $_{\text{[subj.]}}$ bites is big.

Note. Abbreviations in parenthesis indicate semantic roles in the original Spanish sentence, with subj. = subject, obj. = object.

Long-term memory (LTM).

To measure long-term episodic memory, a sentence recognition task was created where children were presented with short texts that consisted of two sentences describing events, and one describing a state, for example, *The car crashed into the bus* (event), *the bus was near the crossroads* (stative), *the car skidded on the ice* (event). Texts were presented auditorily over headphones. At the beginning of the task the participants received a block of 4 stories over, sentence-by-sentence. Each story was separated with a long pause. After finishing the four stories, participants carried out a recognition test in which four sentences were presented for each story (16 sentences total). There were always two sentences that had been presented in the preceding text passage (original sentences), and two foil sentences. Of the foil sentences, one was semantically congruent with the story (*the car was near the crossroads*), another one was incongruent (*the bus skidded on the ice*). The set of 16 recognition sentences (4 for each story) was presented together in the same block, with the order of presentation randomized. The participants were instructed to decide if they thought they had literally read the sentence before and indicate their response by pressing a designated “yes” and “no” button. After finishing the task, the participants received a new block of 4 stories and 16 recognition sentences. Block order was counterbalanced across participants. Percentage scores for accuracy (“yes”-responses to original sentences) and false alarms (“yes”-responses to semantically congruent foil sentences) were calculated, and false alarm rates subtracted from accuracy rates.

Working memory (WM).

To assess verbal working memory, we used a Spanish version of the Daneman and Carpenter’s (1980) reading span task that had been adapted for children (García-Madruga et al., 2013). We followed the García-Madruga and colleagues’ (2013) scoring procedure, which yields a single digit number between 2 and 6, reflecting participants’ reading span.

Reading comprehension.

Materials consisted of 8 texts that differed in difficulty (4 easy, 4 difficult texts) as well as text type (2 narrative and 2 expository texts within each level of difficulty). Participants were presented with 4 texts (1easy-narrative, 1 easy-expository, 1 difficult-narrative, 1 difficult-expository). Children read texts on the computer screen at their own reading pace. Upon completion of each text, 4 questions with 2 answer alternatives (true/false) each were presented on the computer screen to evaluate comprehension and children were instructed to indicate their response by pressing a corresponding button. Questions included literal as well as inferential questions. Correct answer (true/false) and text order were counterbalanced across participants. Accuracy rates for each participant were calculated.

Results

Principal component analysis.

In a first step of analysis, scores from all component tasks (K-BIT fluid and crystallized intelligence, rapid naming, lexical decision task, phonological and morphological awareness, orthographic skill, reading span, LTM and sentence comprehension scores) were submitted to a principal component analysis (PCA) with varimax rotation to reduce data and identify patterns in the component tasks. The value for the Kaiser-Meyer-Olkin criterium (KMO) was .87, and Bartlett's test for sphericity was significant (p <.001), justifying the use of PCA as a means of data reduction. It is important to note that contrary to Factor Analysis, PCA does not assume that individual tasks and measures loading highly on a component are interchangeable indicators of the same latent construct, and the extracted components cannot be interpreted as such. Rather, PCA is a means of data reduction where principal components represent a linear combination of a larger number of underlying variables into fewer dimensions while retaining as much overall variance as possible (e.g., Eid, Gollwitzer, & Schmitt, 2010). PCA is conducive to the aims of this study and is appropriate given the multifaceted nature of our task battery. The use of an orthogonal rotation method - resulting in non-correlated components – was based on our interest in identifying independent sources of variability in our data and often leads to more interpretable solutions.

Two components with eigenvalues above 1.00 were extracted[12]. The appropriate number of components was additionally confirmed through visual inspection of the scree plot. The components accounted for 31 (component 1) and 24 (component 2) percent of overall variance, respectively (rotated solution). Factor loadings on the rotated solution are represented in Figure 1. Reaction times for rapid naming and lexical decision, phonological and orthographic processing, as well as morphological awareness loaded on component 1 (factor loadings between |.54| and |.76|). This component was named *Linguistic processing*. Sentence comprehension, long-term memory, and fluid intelligence loaded on component 2 (factor loadings between .69 and .74); this component was interpreted as reflecting *Memory and Reasoning*. Two variables, namely WM and crystallized intelligence had substantial factor loadings (above .4) on both components.

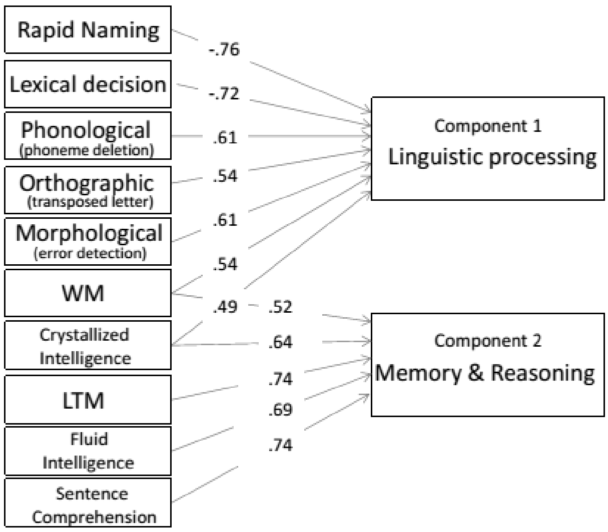

Figure 1. Factor loadings for component tasks [on the left: rapid automatic naming, lexical decision, phonological awareness ("phonological"; phoneme deletion), orthographic skill ("orthographic"; transposed letter), working memory ("WM", reading span), long-term memory ("LTM"), crystallized and fluid intelligence, and sentence comprehension, scores as described in the methods section] on components 1 and 2 (on the right) extracted via principal component analysis. Low factor loadings (<.4) are suppressed.

[12] Similar two-factor solutions were obtained for separate analyses by language status.

Analysis of variance (ANOVAs). Alpha-levels were set to zero and were controlled using the Holm-Bonferroni method (Holm, 1979).

Linguistic processing and Memory & Reasoning.

We carried out two separate 3 x 2 ANOVAs with age (7-8 year olds, 9-10 year olds, 11-14 year olds) and bilingual status (BL vs. ML) as independent variables on extracted factor scores. ANOVAs revealed main effects of age for both components (Linguistic processing: F (2, 138) = 33.95, p <.001, η_p^2= .34, Memory & Reasoning, F (2, 138) = 21.24, p <.001, η_p^2= .24). There were significant linear trends for both components (Linguistic processing: F (1, 88) = 79.81, p < .001, η_p^2 = .48, Memory & Reasoning: F (1, 88) = 35.18, p < .001, η_p^2 = .29), indicating that older children scored higher than younger ones (Linguistic processing in 7-8 yr. olds, M = 2.21, SE = 0.14, in 11-14 yr. olds, M = 3.67, SE = 0.1, Memory & Language in 7-8 yr. olds, M = 2.45, SE = 0.12, in 11-14 yr. olds, M = 3.6, SE = 0.13).

Linguistic processing

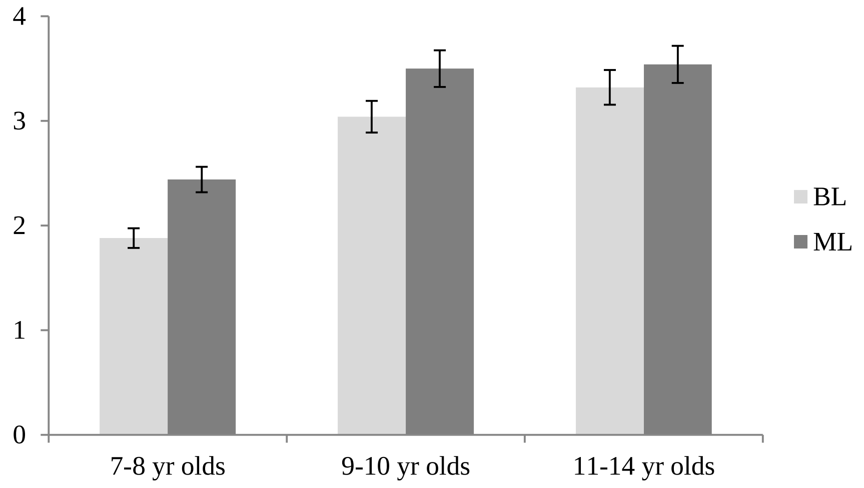

Figure 2. Linguistic processing (component 1) in emergent bilingual (BL) vs. monolingual children (ML) across age groups. The y-axis represents transformed factor scores of component 1. Error bars represent the standard error of the mean.

Memory & Reasoning

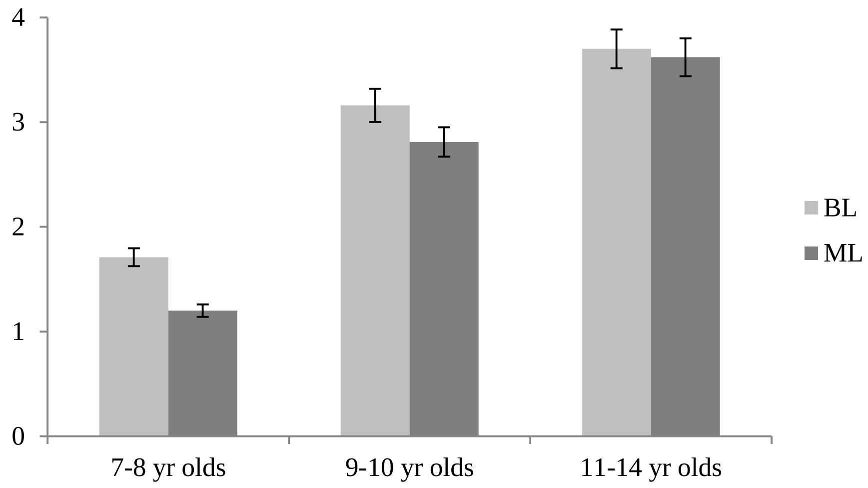

Figure 3. Memory & Reasoning (component 2) in emergent bilingual (BL) vs. monolingual children (ML) across age groups. The y-axis represents transformed factor scores of component 2. Error bars represent the standard error of the mean.

Monolingual children outperformed emergent bilingual children on Linguistic processing, F (1,138) = 16.41, p <.001, η_p^2= .11 (monolinguals, M = 3.27, SE = 0.1, emergent bilinguals, M = 2.77, SE = 0.13), while bilinguals scored higher on the Memory & Reasoning component, F (1, 138) = 4.55, p <.05, η_p^2= .03 (monolinguals, M = 2.84, SE = 0.13, emergent bilinguals, M = 3.2, SE = 0.1). Interactions between age and bilingual status did not reach significance for either component (Fs < 0.68, ps >.10, η_p^2 <.01). Performance for monolingual vs. emergent bilingual children across age is depicted in Figures 2 and 3[13]. Descriptive values and inference statistics for the effect of bilingual status on individual component tasks are represented in Table 4. Most notable, significant main effects were observed for reaction times on the rapid naming and lexical decision tasks as well as morphological awareness (along with a marginally significant effect for phonological

[13] Since extracted factor scores were centered around zero, we carried out a linear transformation for illustration purposes, whereby the absolute value of the minimum out of all extracted values [Min $_{\text{linguistic processing}}$ = -3.02] was added to each individual factor score.

awareness), where monolinguals showed better performance. Emergent bilinguals showed a tendency towards increased LTM.

Table 4.

Means and standard errors of the mean for component tasks in emergent bilingual (BL) and monolingual (ML) children, and inference statistics (F, p and η_p^2) in a 3 x 2 ANOVA with age[14] and bilingual status as independent variables for between-group comparison.

	M (BL)	*M* (ML)	*F* (1, 138)	*p*	η_p^2
Rapid naming (in seconds)	27.79 (0.74)	24.74 (0.67)	12.8	<.001	.09
Lexical decision (Words, in ms)	744.06 (17.84)	702.75 (17.11)	4.41	<.05	.03
Lexical decision (Nonwords, in ms)	855.25 (22.07)	818.83 (22.25)	2.09	>.05	
Phonological	77.33 (2.44)	82.43 (2.28)	3.07	.08	.08
Orthographic	-16.94 (2.28)	-16.85 (1.86)	0.00	>.05	<.01
Morphological	62.76 (3.21)	74.48 (2.55)	8.76	<.01	.06
Sentence comprehension	65.86 (2.15)	62.68 (2.34)	1.13	>.05	<.01
Crystallized Intelligence	49.14 (1.24)	48.63 (0.99)	0.07	>.05	<.01
Fluid Intelligence	30.61 (0.77)	29.96 (1.11)	0.31	>.05	<.01
WM	3.30 (0.06)	3.37 (0.06)	1.16	>.05	<.01
LTM	36.37 (2.97)	27.39 (3.64)	3.48	.06	.03

Note. Measures of individual tasks include: rapid naming times (objects and letters) and lexical decision times for words and nonwords, % correct in the phoneme deletion task (phonological awareness; *phonological*), mean accuracy minus false alarm % for gender and number error detection (morphological awareness; *morphological*), % correct for identical pairs minus % correct for transposed letter pairs (*orthographic)*, complex structures in the syntactic comprehension task (sentence comprehension), K-BIT raw scores for crystallized and fluid intelligence, reading span (WM) and hit minus false alarm rates in the long-term memory (LTM) task.

[14] All component tasks were subject to significant age effects (all Fs $\geq$ 4.34, ps $\leq$ .05, $\eta_p^2 \geq$ .06), with significant linear trends (all Fs $\geq$ 8.61, ps $\leq$ .01, $\eta_p^2 \geq$ .09). Interactions between age and bilingual status were not significant (Fs $\geq$ 2.86, ps $\leq$ .05, $\eta_p^2 \geq$ .04).

Reading comprehension.

We conducted a 3 x 2 x 2 mixed ANOVA on reading comprehension scores. Scores were collapsed across text type (narrative vs expository), as there were no significant differences, F (1, 138) = 1.89, p >. 05, η_p^2 = .01. Analyses thus included one within-subjects variable, difficulty, with two levels (easy vs. difficult), and two between-group variables, namely, age, with three levels (7-8 year olds, 9-10 year olds, 11-14 year olds), and bilingual status (BL vs. ML). There was a significant effect of difficulty, F (1, 138) = 183.66, p < .001, η_p^2 = .57, with accuracy rates being lower for difficult texts (M = 52.95, SE = 2.06) than for easy texts (M = 75.26, SE = 1.81), as well as age, F (2, 138) = 18.55, p < .001, η_p^2 =.21, with older children (M = 78.57, SE = 2.64) outperforming younger ones (M = 55.38, SE = 2.76) as evidenced by a significant linear trend, F (1, 88) = 36.61, p < .001, η_p^2 =.29. There was no main effect of bilingual status, F (1, 138) = 0.23, p > .10, η_p^2 < .01, as emergent bilingual and monolingual children showed a similar level of overall performance (monolinguals, M = 64.58, SE = 2.5, emergent bilinguals, M = 63.63, SE = 2.48). None of the interactions were significant (all Fs ≤ 1.79, ps >.10 and η_p^2 s≤.03). See Figure 4 for illustration.

Reading comprehension

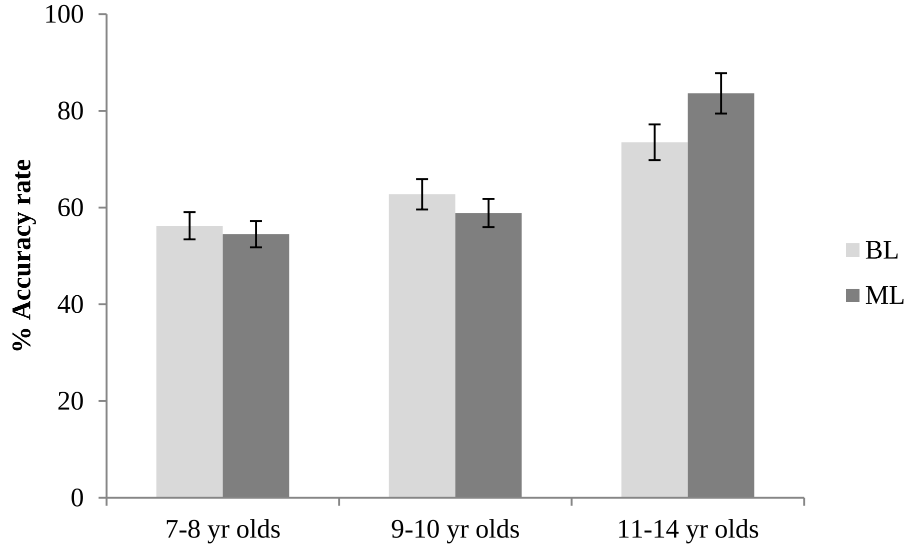

Figure 4. Reading comprehension in emergent bilingual (BL) vs. monolingual children (ML) across age groups.

Regression analyses.

Linear regression with reading comprehension scores as dependent variable and Linguistic processing and Memory & Reasoning as predictors were carried out in order to determine to which extent both components contribute to reading comprehension at the text-level. Based on the entire sample, both components explained significant variance (Memory & Reasoning, b = 7.68, t = 4.66, p <.001, ΔR^2 = .13, Linguistic processing, b = 6.81, t = 4.01, p <.001, ΔR^2 = .11). Separate regression analyses by language status revealed differential contributions of both factors for bilingual vs. monolingual children. In bilingual children, more variance was explained by Linguistic processing, b = 7.97, t = 3.49, p =.001, ΔR^2 = .13, while the predictive effect of Memory & Reasoning was marginally significant, b = 5.15, t = 1.87, p =.07, ΔR^2 = .05. In monolinguals, on the other hand, the amount of variance explained was larger for Memory & Reasoning, b = 9.91, t = 4.88, p <.001, ΔR^2 = .25, compared to Linguistic processing, b = 7.18, t = 2.73, p =.008, ΔR^2 = .10. Figure 5 illustrates the relationship between each factor and reading comprehension within both groups.

Regression analyses

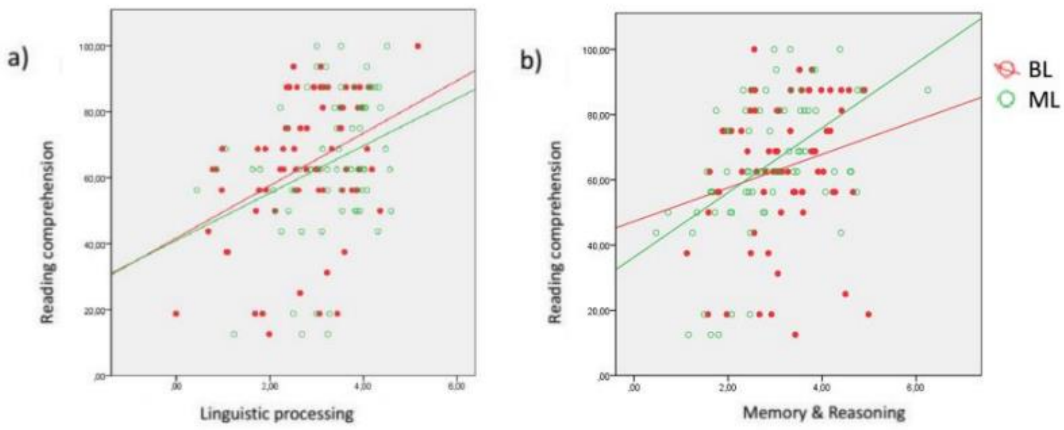

Figure 5. Reading comprehension in function of scores for a) Linguistic processing and b) Memory & Reasoning for emergent bilingual and monolingual children.

Discussion

The present article investigates the costs and benefits of monolingual vs. L2 immersion education for reading comprehension. Our design allows us to integrate developmental, educational and cognitive approaches, as text-level reading comprehension is a complex cognitive skill composed by a number of underlying component skills and taught as part of school curricula. To this end, we assessed L1-Spanish children enrolled in an L2-English immersion program and monolingual Spanish age peers at different developmental stages in L1 text comprehension and a number of related skills (vocabulary, lexical access in production and comprehension, phonological and morphological abilities, verbal Working Memory and Long-term Memory, and sentence-level syntactic comprehension). English immersion education has been increasingly implemented in the Spanish school system and will continue to do so throughout the next years, making questions regarding the consequences particularly relevant. L2 immersion students receive less explicit instruction in L1 literacy skills than monolinguals and unlike these, divide their linguistic exposure between two languages. In addition, current cognitive-linguistic theories recognize that bilinguals activate both languages in parallel, leading to increased cognitive load and slower lexical access when processing within-language, compared to monolinguals (e.g., Green, 1998). From this theoretical perspective, a potential concern is that L2 immersion education might present a certain drawback or increased vulnerability for L1 development and literacy acquisition.

Analyses revealed that overall, emergent bilinguals did not differ from their monolingual counterparts in terms of L1 text-level reading comprehension. All children improved their L1 reading skills with age at a similar pace, regardless of the language of formal instruction. Interestingly, even though both groups performed similarly on text-reading comprehension, they differed in selected skills and abilities that are known to contribute to reading comprehension.

The principal component analysis (PCA) allowed us to categorize subskills underlying reading comprehension into two broader components. The first component, which we named “Linguistic processing”, is mostly based on reaction times for rapid naming and lexical decision, phonological and orthographic processing, as well as morphological awareness. These measures require processing and attending to the lexical and sublexical units that form the basis of written text (for example, the speed or fluency of lexical access from written words vs. pictures). Sentence comprehension, long-term memory, and fluid intelligence loaded on the second component, which we refer to as “Memory & Reasoning”. Sentence comprehension, especially for complex and noncanonical sentences, reflects computation and integration processes in long-term working memory (Kidd, 2013, Boyle, Lindell, & Kidd, 2013, Lewis, Vasishth, & Van

Dyke, 2008, Montgomery et al., 2008). Two measures, Working Memory and crystallized intelligence, had high factor loadings on both components. High loadings of the same task on multiple principal components can sometimes complicate interpretation, but in this case can be easily explained. The crystallized intelligence scale of the K-BIT consists of a vocabulary test; as a measure of lexical knowledge and semantic memory in the language domain, it should load on both components. Similarly, reading span is a measure of Working Memory with its executive component, but also draws heavily on time-limited language-based processing (Towse, Hitch & Hutton, 1998). Apart from fluid intelligence, the measures loading highly on the second component thus capture different aspects of memory. Overall, the Memory & Reasoning component reflects aptitude and ability to learn and retain new information, which in reading comprehension are needed to infer information from text, construct and maintain a mental representation (see Oakhill, Cain, & Bryant, 2003, for a discussion of different components of reading comprehension). Since both components are orthogonal, thus sharing no variance, the PCA allows us to separate these two aspects of reading comprehension. In sum, the resulting components align with theoretical models of reading comprehension that describe two important classes of underlying component factors: on the one hand, purely linguistic processes and abilities whose effects are often mediated via lexical reading skill (such as phonological or orthographic skills), and on the other hand, cognitive abilities that are not necessarily tied to a specific domain (such as working memory or inference making, e.g., Oakhill et al., 2003). Thus, the resulting structure captures these theoretical components and extends them to bilingual reading.

Although monolinguals and bilinguals obtained similar scores in the reading task, they differed in terms of the two components. Thus, monolingual children outperformed emergent bilingual children on Linguistic processing, while bilinguals scored higher on the Memory & Reasoning component. The lower scores in L1 skills obtained by children undergoing L2 immersion replicate previous findings, and probably reflect (i) the reduced exposure to formal instruction and (ii) the need to cope with language co-activation. A closer look at the group differences in the specific skills that form the linguistic component supports this idea. Thus, monolinguals surpassed emergent bilinguals in rapid naming and lexical decision speed. Slower lexical access is often found in bilinguals (e.g., Ivanova & Costa, 2008, Michael & Gollan, 2005, Yan & Nicoladis, 2009) and has been associated with the fact that bilinguals activate their two languages in parallel (Poarch & van Hell, 2012, Thierry & Wu, 2007). Language co-activation forces bilinguals to negotiate the attentional demands of both languages and avoid intrusions from the unintended language. Most theories agree that this process involves inhibiting or otherwise reducing the activation of the non-target language, leading to slower naming times (e.g., Costa, La Heij, & Navarrete, 2006, Green, 1998). Here, we observe an effect on children's continuously dominant L1. This finding is in line with Linck, Kroll, and Sunderman (2009), who report a relative slowdown of L1 verbal processing in university students immersed in an L2 during a study abroad program, but to our knowledge, this kind of effect has not yet been reported in regards to L2 immersion students.

Also among the tasks that loaded highly on the linguistic component, and unlike other studies (e.g., Bialystok, Peets, & Moreno, 2014), we did not find any enhancement of metalinguistic skills in emergent bilinguals, but an advantage for monolinguals in morphological awareness. This unexpected result could be due to the specific language combination in our study. From a theoretical viewpoint, metalinguistic advantages in bilingual children can be explained as due to the fact that between-language differences draw children's attention to the rules and regularities of a language and aid their understanding of the separation of form and content (e.g., Cummins, 1978, see also Marinova-Todd, 2012). However, most of the existing research evaluated immersed bilinguals in an L2 (French) with a richer morphology than their L1 (English). In contrast, the language of formal instruction of our bilingual sample (L2-English) is morphologically simpler than the L1, Spanish: modern English does not possess grammatical gender, nor does it require plural marking for adjectives. In fact, as illustrated by the example above, the gender and number violations in Spanish implemented in the morphological awareness task have no English equivalents. This might explain why in this case, the experience with a second language did not yield immersion children an advantage in morphological awareness, and why the latter might, in fact, be better acquired by monolinguals with higher exposure to the L1 in formal education. This result highlights the necessity to account for language pairs when evaluating linguistic (or metalinguistic) skills. Overall, the greater difficulties emergent bilinguals experience in processing L1 lexical and sublexical forms likely reflects exposure effects (Oller & Eilers, 2002) in addition to increased cognitive load resulting from language co-activation.

Regarding the second component, our results indicate that emergent bilinguals outperformed monolinguals on the Memory & Reasoning component. Memory capacity has been less central in the literature on the consequences of bilingualism and it therefore remains to be seen whether this finding extends across different samples of bilinguals or immersion students. For Working Memory, previous results have been mixed, although a bilingual advantage has sometimes been observed, especially when executive demands are high (Morales, Calvo, & Bialystok, 2013) and linguistic deficits are taken into account (Blom, Küntay, Messer, Verhagen, & Leseman, 2014). This might explain why in our data, a bilingual advantage emerged for principal component scores, but not for individual task scores. On the other hand, there has been one report of increased associative memory in young adults after having undergone an intensive L2 immersion program (Mårtensson & Lövdén, 2011), supporting the idea that highly demanding language-learning environments not only rely on memory skills, but also modulate and enhance them.

Importantly, the poorer performance of bilinguals in the linguistic component skills did not result in reduced performance on text-level comprehension compared to monolingual controls. This is particularly remarkable given the result of the regression analyses. Individual differences in reading comprehension by language status (bilinguals vs. monolinguals) were predicted to a larger extent by the component in which the respective group showed greater difficulties: Linguistic processing for bilinguals and Memory & Reasoning for monolinguals. This finding is intriguing: on the one hand, the pattern observed for emergent bilingual children resembles one that is more typical for younger children, characterizing them as less experienced L1 readers. Typically, within the earlier grades of elementary school, individual differences in reading comprehension depend mainly on lower-level linguistic (e.g., lexical, orthographic and phonological) abilities whereas in older children, it is mostly higher-level, conceptual processes that determine outcome differences (e.g. Diakidoy et al., 2005, Tilstra et al., 2009). On the other hand, the reading comprehension of emergent bilingual children did not lag behind their monolingual peers, and as previously mentioned, they excelled on the Memory & Reasoning component, indicating a high level of cognitive ability and capacity that would not be present in younger readers. Thus, the cognitive advantage in Memory & Reasoning abilities in the bilingual groups may have helped them to compensate for deficits in Linguistic processing. In addition, the fact that less overall variance in reading comprehension scores was accounted for by the two principal components in the bilingual group suggests that linguistic deficits in emergent bilinguals might be compensated via multiple processes, some of which are not captured by the 2-component structure (for example, more purely executive, non-linguistic processes, or more complex conceptual processes not measured here).

In summary, the present study contributes to the existing literature in a several aspects. First, we approached the study of reading comprehension from a hierarchical perspective, evaluating children on the complex skill level as well as on underlying cognitive and linguistic components, represented by two principal components. Virtually all tasks that are currently available to assess cognitive development and performance behaviorally reflect multiple processes, which poses a challenge to research on the cognitive consequences of bilingual development and education: selective effects are often difficult to localize. Using principal component analysis on our task battery made it possible to identify distinct sources of variance within the same tasks that are associated with opposing outcome patterns and that would not have been dissociable otherwise (see also Engel de Abreu, 2011, for a similar application of PCA). On the other hand, it has been mostly basic cognitive processes that have been reported to be subject to the effects of bilingualism, which is informative on a theoretical level but leaves open questions regarding the practical relevance. Linking the level of basic processes to complex skill by virtue of a cognitive components perspective might be a way to build on existent evidence to gradually increase ecological validity of research findings. Likewise, this approach can be transferred to alternative group and/or individual differences in the acquisition of reading comprehension and might also apply to other complex skills such as mathematics.

Secondly, we extend the existing research on immersion education. Previous research into the academic and cognitive outcomes of L2 immersion schooling has largely been limited to the Canadian system, with L1 English as the home language and L2 French as the school language. The current study is based on a relatively unstudied language pair in this context: L1-Spanish and L2-English. L2 immersion education poses a unique path to bilingualism, and in this sense, this research also extends some of the findings from early and more balanced bilinguals. In this regard, an advantage of studying immersion education is that both groups of children had comparable socioeconomic statuses and shared the same cultural background, and unlike in many previous studies, neither bilinguals nor monolinguals were immigrants. These two aspects have been claimed as a source of variability in bilingual studies (e.g., Morton & Harper, 2007), which is reduced here.

Unfortunately, as bilingual status, and in this case, choice of school, cannot be randomly assigned, this does not preclude the possibility that there might be between-group differences beyond L2 immersion experience. Further longitudinal research might help to clarify to what extent pertinent effects depend on pre-existent group differences. Thirdly, our results suggest that the equivalent performance on a specific complex activity such as reading comprehension is modulated by differential capacities in the specific skills necessary to succeed. Thus, even when particular linguistic skills seem to be delayed by L2 immersion schooling, other processes appear to compensate so bilingual children achieve monolingual-like performance on text-level comprehension. This finding encourages a positive outlook on the flexibility of literacy acquisition in general. The presence of compensation effects in light of selective costs and benefits in different populations suggests that readers with different learning histories and from different language backgrounds are able to draw from individual resources to compensate areas of deficit, at least as regards typically developing children. To the extent that these findings can be generalized to special needs populations these outcomes can also inform intervention studies in reading, and, specifically, add support for resource- rather than deficit-oriented intervention strategies. Future studies should further investigate non-linguistic components, as well as more specific text inference and integration skills that contribute to the development of reading comprehension.

In conclusion, L2 immersion education does not have any detrimental consequences for the development of text reading comprehension on the native language of Spanish children enrolled in English immersion schools. As for an educational viewpoint, children enrolled in immersion programs showed similar skills in L1 reading comprehension as monolinguals. Receiving formal instruction in a second language was associated with decreased performance on specific language skills such as rapid naming, lexical decision and morphological awareness. In exchange, emergent bilinguals showed better Memory &

Reasoning skills, which seem to compensate for linguistic deficits in reading comprehension. In terms of its methodological contributions, our findings highlight the need to carefully consider task selectivity as well as participant characteristics, such as the "type" of bilingualism or language combination, and point a way to deal with problems of task impurity through statistical analyses.

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Experimental Series II (Experiments 3 & 4)

Experiments 3 & 4. Adaptive control in late bilinguals and L2 learners: The role of active immersion and language switching[15]

In the present study, we investigate to what extent enhanced executive control in bilinguals may depend on individually variable factors such as the degree of L2 immersion (or more generally, immersion in a non-dominant language) and language switching habits. We hypothesized that these factors might selectively affect specific executive function mechanisms and distinguish between interference control, conflict monitoring, and cognitive flexibility. In Experiment 3, the effects of active immersion and language switching habits were assessed longitudinally in a sample of 34 young adult trilinguals before and after being immersed in a multilingual environment. Experiment 4 featured a cross-sectional design with a total of 73 participants who belonged to one of three groups: (1) bilinguals with a high degree of active immersion in their L2; (2) bilinguals with a lower degree of active immersion in their L2; and (3) monolinguals. Across the two experiments, we observed a selective effect of active immersion on interference control, reflected by reduced interference costs at post-test compared to pre-test (Experiment 3), and in more immersed bilinguals compared to monolinguals, with less immersed bilinguals performing between the two other groups (Experiment 4). In addition, regression analyses suggested that degree of active immersion was associated with better interference control, and to a lesser degree, conflict monitoring, while language switching habits were associated with cognitive flexibility.

[15] Hansen, L. B., Kroll, J. & Bajo, T. (submitted). Adaptive control in late bilinguals and L2 learners: The role of active immersion and language switching.

There is an ongoing debate regarding whether, and how, bilingualism affects cognitive abilities outside the language domain. A large body of data suggests that bilinguals excel on nonverbal measures of executive control (e. g., Adesope, Lavin, Thompson & Ungerleider, 2010, Bialystok, 2001, Bialystok, 2009, Bialystok, Barac, Blaye & Poulin-Dubois, 2010, Bialystok & Craik, 2010, Hernández, Costa & Humphreys, 2012, Morales, Gómez-Ariza & Bajo, 2013, Prior & MacWhinney, 2010). This effect has been observed across lifespan development (e.g., Bialystok, Craik, Green & Gollan, 2009, Bialystok, Craik & Luk, 2012, Bialystok, Martin & Viswanathan, 2005, Craik & Bialystok, 2006), and has been associated with structural brain changes including increased grey matter density or white matter integrity in areas involved in language and executive control (for a review, see Li, Legault, & Litkofsky, 2014). A common interpretation of these data has been that enhanced domain-general executive control in bilinguals - relative to monolinguals - reflects a structural and functional adaptation to the continuous demands of managing two languages relative to one (for a recent integrative perspective, see Buchweitz & Prat, 2013). Co-activation of the non-target language (Blumenfeld, & Marian, 2007, Martin, Dering, Thomas, & Thierry, 2009, Spivey & Marian, 1999, Thierry & Wu, 2007) and consequent interlanguage conflict (Hoshino & Thierry, 2011, Marian & Spivey, 2003a, 2003b, for review, Kroll, Bogulski & McClain, 2012) have been discussed as likely sources of enhanced executive demand for bilingual language processing.

On the other hand, the validity and scope of the postulated effects are not beyond dispute. Increasing numbers of studies provide evidence against a bilingual advantage on some of the most-cited behavioral paradigms in this context, like task switching or interference tasks (Antón et al., 2014, Duñabeitia et al., 2014, in press, Hernández, Martin, Barceló, & Costa, 2013, Kirk, Scott-Brown & Kempe, 2013, Morton & Harper, 2007, Namazi & Thorardottir, 2010, Paap & Greenberg, 2013). Overall, the literature speaks to a nuanced effect that can sometimes be quite difficult to capture (Valian, 2015). One approach to better account for the seemingly inconsistent data has been to define more clearly the particular conditions under which a bilingual advantage is predicted. Bilinguals differ on many factors including language history, proficiency, and most importantly, their habitual use of multiple languages (see Grosjean, 1998, for an overview). Thus, a bilingual may have known two languages all their lives or even be very proficient in them, but may nevertheless mostly communicate monolingually in their daily lives.

According to the recently proposed adaptive control framework (Green & Abutalebi, 2013), all bilinguals do not experience the same enhanced executive demands in their daily interactions, and cognitive adaptation effects may be proportionately related to these demands. In a similar line of argument, Macnamara and Conway (2014) proposed that what determines adaptive change to the executive system is the degree of *bilingual management demand*, that is, the amount of experience with complex linguistic situations that require negotiating the attentional demands of multiple languages. In their study - the first one to observe the cognitive effects of bilingualism longitudinally- bimodal bilinguals showed significantly improved executive control and working memory after two years of practice in simultaneous ASL-to-English interpreting (for a similar finding based on a cross-sectional design, see Yudes, Macizo & Bajo, 2012). Conversely, lapsed bilinguals who no longer use multiple languages in their daily lives, show a less pronounced cognitive advantage than participants who continue to speak both languages regularly, relative to monolinguals (Bogulski, Rakoczy, Goodman, & Bialystok, 2015). Thus, only bilinguals who are exposed to and actively use both languages can be expected to show an executive advantage. These factors directly relate to the degree of “bilingual management demands”.

Interestingly, bilinguals in the two studies mentioned above (Macnamara & Conway, 2014, Yudes et al., 2012) were sequential bilinguals. Although executive advantages have been observed for both early bilinguals (Luk, de Sa, & Bialystok, 2011) and sequential bilinguals who acquired their L2 later in life (e.g., Bak, Vega-Mendoza, & Sorace, 2015, Tao, Marzecová, Taft, Asanowicz, & Wodniecza, 2011, Vega-Mendoza, Bak, & Sorace, 2015), limited proficiency is a factor that is likely to add to the cognitive-executive demands of language processing (i.e., increasing linguistic management demands). When proficiency is low and L2 acquisition is at its beginning stages, L2 processing is less automatic and requires a large amount of executive and memory resources in and by itself (e.g., Abu-Rabia, 2003, Dussias & Piñar, 2010). In addition, interference from the L1 to the L2 is stronger than vice versa, especially when there is a large proficiency asymmetry (e.g., Jiang & Forster,2001, Keatley, Spinks, & De Gelder, 1994, Meuter & Allport, 1999, Yamasaki & Prat, 2014, see also Green, 1998). A recent longitudinal study shows that in young adult learners, L2 processing taxes cognitive control especially at early stages of L2 acquisition (Grant, Fang, & Li, 2015). To sum up, based on the findings discussed thus far, a key factor associated with cognitive benefits in bilinguals may be active bilingual immersion, especially in the weaker language.

Only a few studies have systematically examined the consequences of immersion in the less dominant language for language processing and control (Baus, Costa, & Carreiras, 2013, Linck, Kroll, & Sunderman, 2009). In each case, evidence was reported for reduced access to the native or more dominant language in both production and comprehension during L2 language immersion. Although a number of different interpretations have been offered for the observed cost to the L1 during immersion, the effect itself can be understood as the requirement to regulate the more dominant language in the face of increased activation of the second or less dominant language. If immersion facilitates the acquisition of this regulation skill, then it may also confer some benefits to language and cognitive processing more generally.

An additional factor regarding the effects of bilingualism on executive control is that bilinguals may differ not just in the degree but also in the type of executive resources they recruit to meet language control demands in their daily interactions. Depending on the language context in which a bilingual is immersed, language processing might strain distinct control mechanisms, translating to differential executive advantages that emerge over time, following the postulates of the adaptive control hypothesis (Green & Abutalebi, 2013). While two bilinguals might use both languages on a daily basis, they might differ in whether they use each one in a separate context, for example, at home vs. at work or within the same environment. The specific control demands associated with linguistic processing within these two settings (single language contexts or mixed language contexts) will arguably differ. For instance, communicating efficiently in a single language context mainly requires mechanisms such as conflict monitoring and inhibition that help overcome cross-linguistic interference and thus, avoid intrusions from the non-target language (Green & Abutalebi, 2013). In mixed language contexts, "bilingual management demands" are further increased due to two factors. On the one hand, the overt presence of several languages increases cross-language conflict (Christoffels, Firk & Schiller, 2007, Gollan, Schotter, Gomez, Murillo, & Rayner, 2014). Furthermore, in addition to managing interference from a non-target language, bilinguals in mixed contexts may use both languages to address different speakers, and thus need to keep up with recurrent changes of the target language dependent on external cues. In this situation, bilingual speakers need to balance efficient interference control and flexible release of inhibition to ensure rapid language task reconfiguration (disengagement and re-engagement of control mechanisms) to enable both stability and flexibility of the target language according to the situation (Green & Abutalebi, 2013).

Empirical evidence supports the idea that adaptive effects in flexible control mechanisms such as set shifting are selective to bilinguals immersed in mixed language contexts who frequently switch between languages (see Prior & Gollan, 2011, regarding reduced switch costs, see Soveri, Rodriguez-Fornells, & Laine, 2011, regarding reduced mix costs), although interference control also appears to be enhanced in this group, compared to bilinguals in single language contexts (Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2016). The idea that different bilingual contexts are associated with different cognitive demands adds another dimension to the debate regarding which aspect of the executive control system is modulated by multiple language use (for different proposals, see, e. g., Bialystok & Majumder, 1998, Colzato, van Wildenberg, Bajo & Paolieri, 2008, Costa, Hernández, Costa-Faidella & Sebastian-Gallés, 2009, Hernández, Costa & Humphreys, 2012, Hilchey & Klein, 2011, Morales et al., 2013, Prior, 2012, Stocco Yamasaki, Natalenko, & Prat, 2014). In addition to bilingualism itself, both the degree of active immersion and the individual immersion context (single vs. mixed language context) must be taken into account.

In sum, the cognitive effects of bilingualism appear to be both graded and multifaceted (e.g., Kroll & Bialystok, 2013, Luk & Bialystok, 2013). Cognitive adaptation effects - measurable in terms of a benefit on nonlinguistic executive tasks – likely depend on individual experiences with complex linguistic situations over an extended amount of time. Following the recent literature, factors that increase executive demands for bilingual language processing and contribute to measurable cognitive adaptation effects are immersion in and active use of a less proficient L2 (Macnamara & Conway, 2014, Vega-Mendoza et al., 2014), and exposure to mixed language contexts with frequent changes of the target language (Green & Abutalebi, 2013, Verreyt et al., 2016). In addition, mechanisms of interference control such as inhibition and conflict monitoring, might more likely be subject to adaptive effects than mechanisms that enable flexibility and change between task sets, such as set shifting, which might more selective to bilinguals who are required to frequently change languages within the same context of their linguistic community. The present research aims to put some of these ideas to test. To this end, we assessed bilinguals who differed in their degree of bilingual immersion. The primary hypothesis, that bilingual executive function benefits depend on the degree of L2 immersion, was tested in two experiments, one longitudinal (Experiment 1) and the other cross-sectional (Experiment 2). A secondary aim was to evaluate the effects of language switching habits. In line with the predictions of the adaptive control hypothesis (Green & Abutalebi, 2013), we expected to find more general effects of bilingual immersion on measures of inhibition and conflict monitoring (Simon and Flanker paradigms), and a selective effect of language switching frequency on measures of cognitive flexibility (in this case, switch and mix costs).

Experiment 3

Methods

Participants and Procedure

Forty native speakers of German enrolled in a study-abroad-program at the University of Granada took part in this study. All participants were full-time students in German universities. They were tested shortly upon arrival, 2 to 4 weeks after the beginning of their stay abroad (pre-test session) and again 8 months into their stay (post-test session). Thirty four of the 40 original participants returned for the post-test session of the experiment (28 females, mean age: 22.74, *SD* =1.58). Participants were given the same version of all tasks in the pre and post-test sessions. At pre-test, all participants were proficient speakers of English (L2), which they had acquired between the ages of 9 and 12 (*M* = 10.41, *SE* = 0.13), and were beginning learners of Spanish (L3). They had been enrolled in a Spanish class during the semester prior to their stay abroad. All participants reported having received formal instruction in another language, either French or Latin, but not having any functional knowledge of these languages. Participants' language experience and context of language use were assessed using the Language History Questionnaire (LHQ, Version 2, Li, Sepanski & Zhao, 2006) and a trilingual switching questionnaire similar to the bilingual switching questionnaire (BSWQ, Rodriguez-Fornells, Krämer, Lorenzo-Seva, Festman, & Münte, 2012) and at pre- and post-test. During the pre-test session, participants were asked to complete the same version of the language history questionnaires twice, once with their home environment and language use in mind and once in regards to their current interactional context and habits since the beginning of the study. Participants reported communicating almost exclusively in their L1, German, and never switching between their L1 and another language previous to the immersion period. They reported that the beginning of the immersion period was marked by a decrease in L1 use and increase of both L2 and L3 use; the distribution of language use remained similar between the pre- and post-test session. Self-assessed L3 proficiency was significantly higher at post-test compared to pre-test, F (1, 33) = 28.78, p < .001, η_p^2 = .47, while L2 proficiency remained at a similar level, F (1, 33) = 2.77, p > .05, η_p^2= .08. Nearly all participants reported engaging in language switching in their immersion environment to some degree, both at the pre-test and the post-test session. All participants reported regularly or frequently being exposed to dual language contexts (environments that require speaking to different speakers in two different languages) and about 30% reported being occasionally exposed to triple language contexts during their stay abroad (pre and post-test session). See Table 1 for language background variables in the home environment and immersion environment reported at post-test.

Table 1.

	Prior to stay	Post-test
L2 Proficiency	5.26 (0.12)	5.34 (0.13)
L3 Proficiency	3.31 (0.14)	4.34 (0.13)
Switching Frequency	-	3.04 (0.12)
Switching Automaticity vs. Control	-	4.12 (0.05)
Combined L2 and L3 use %	0% (0.00)	56 % (2.95)

Note. Means and standard errors (parenthesized) for linguistic proficiency, active immersion and language switching habits previous to immersion and at post-test. Proficiency scores represent self-assessed L2 and L3 abilities on a 7-point scale with (1) - very poor, (2) - poor, (3) - fair, (4) - neutral, (5) - good, (6) - very good, (7) - native-like), averaged across reading, writing, listening and speaking. Switching frequency and automaticity/control are assessed on a 5-point scale (regarding automaticity/control, small values represent automatic switching, large values controlled switching).

Tasks & Variables

Language questionnaires. We used a modified version of the LHQ (Li et al., 2006), in order to assess age of acquisition and language experience, self-assessed proficiency in the L1, L2, L3 and any other languages (measured on a 7-point scale), percentage of language use per day, frequency of exposure to multiple language contexts and language switching (yes/no). In addition, participants were given a trilingual switching questionnaire for further assessment. Similar to the BSWQ (Rodriguez-Fornells et al., 2012), this questionnaire allowed us to assess (a) the overall frequency of switches, and (b) the automaticity vs. controlled nature of switching on a scale from 1 to 5 (for b) small values represent automatic switching and high values represent controlled switching). At the time of the study, the final version of the BSWQ had not been published and the questionnaire was adapted from a description of the BSWQ provided by Soveri et al. (2011). To take into account switching between three languages we first assessed self-reported switching from and into each individual language, and then calculated a mean score for switching frequency overall.

Simon Task. On the Simon task, participants saw a blue or red square presented over a white background on the screen and were instructed to press corresponding keys marked by colors and located on the left vs. right-hand side of the keyboard) as quickly and accurately as possible. Stimuli could appear in the center, the left side, or the right side (for both sides, alignment varied between 42 and 58%) of the screen. Thus, stimulus location and color mapping could be congruent (for example, a red square appearing right of the center for red indicating a right-hand button press), incongruent (e.g., a blue square appearing right of the center for blue requiring a left-hand button press) or neutral (a centrally located red or blue square). Each trial started with a fixation cross (350ms.), followed by a blank screen (150ms), presentation of the stimulus and another blank screen (850ms). Stimuli remained on the screen for 2000ms or until participants pressed a response button.

Flanker Task. In addition, we used an Eriksen flanker task (Eriksen & Eriksen, 1974, see also Friedman & Miyake, 2004). In this task, letters appeared on the screen and participants were asked to press a left key if the critical target letter was an S or a C and a right key if it was an H or a K. There were four different types of trials. In the baseline condition, target letters were presented in isolation (simple trials, e.g., “K”), otherwise, centrally located target letters were surrounded by noise letters (flankers) that were either the same as the target letter (congruent trials, e.g., “KKKKKKK”), response compatible (compatible trials, e.g., “HHHKHHH”), or response incompatible (incompatible trials, e.g., “SSSKSSS”). The task comprised 160 trials with an equal number of trials per condition, preceded by 20 practice trials. Trials order was randomized with the restriction that the same condition could not appear on more than 3 consecutive trials and flanker letters in any given trial n-1 could not appear as targets on the following trial n. On each trial, stimuli in the form of black letters over a white background appeared, preceded by a blank screen (1000 ms.) and a fixation cross (500 ms), remaining on the screen until participants indicated their response by pressing a corresponding key. Interference effects were calculated as the difference in reaction times between the simple and incompatible conditions (see Friedman & Miyake, 2004).

Task Switching. We used a color-shape task switching paradigm (Rubin & Meiran, 2005, see also Prior & MacWhinney, 2010). Target stimuli were circles and triangles that could be either red or green, and there were two response keys. For the color task, participants had to press one of two keys on each trial according to the color of the stimulus (e.g., right key for red, left key for green), for the shape task, they had to press keys according to the shape (e.g., right key for a circle, left key for a triangle). A pre-target cue (either a color gradient or a row of small geometrical shapes) indicated whether the present trial was a color or shape trial. There were three different blocks of the task: the first block was either a color or a shape trial (simple task block, order was randomized across participants, whereas the third block was comprised of both color and shape trials (mixed block, 50% each). Half of the trials in the mixed block were switch trials (i.e., a color trial following by a shape trial or vice versa), the other half were stay trials (e.g., a color trial following a color trial). Overall, there were 80 switch trials, 80 stay trials, and 160 single task trials (80 color trials, 80 shape trials), and each block was preceded by 20 practice trials. Each trial started with a fixation cross (350 ms), followed by a blank screen (150 ms). Subsequently, the task cue appeared on the screen for the duration of 200 ms or 1200 ms, followed by the target stimulus presented in the center of the screen over a black background. Target stimuli remained on the screen during 4000 ms or until participants pressed a response button. During practice trials, participants received feedback regarding the accuracy and speed of their responses.

Scoring and data filtering

A concern for studies on bilingualism and executive control is that often a number of tasks are measured, increasing the probability of a Type 1 error. Therefore, and in order to carry out a more economical analysis, we calculated composite scores for those variables that conceptually measure the same mechanism, namely the Simon and Flanker Cost Scores, both representing interference control, and overall reaction time scores on the Simon and Flanker task, representing conflict monitoring. To obtain composite scores, all scores were first transformed into z-scores, and mean scores were calculated for those measures representing the same construct. Previously, reaction time data were filtered by removing trials on which participants had responded incorrectly or that were more than 2.5 standard deviations above or below individual means. Separate repeated measures ANOVAs were calculated for interference cost (RTs for incongruent minus congruent/simple trials on the Simon and Flanker task), conflict monitoring (overall RTs on the Simon and Flanker task), switch cost (RTs for switch minus non-switch trials on the color-shape task switching paradigm), and mix cost (RTs for mixed minus simple block trials on the color-shape task switching paradigm).

Pilot study

To rule out possible training effects that would explain altered performance at the post-test session, we first conducted a pilot study with a monolingual sample. Participants were 36 native speakers of Spanish (29 females, mean age: 21, 95, *SD* =1.56). Four additional participants were excluded from the sample because they reported being early bilinguals of Spanish and another language (2 Basque speakers, 1 Catalan speaker, 1 Valencian speaker) after initially signing up for the study as Spanish monolinguals. The pilot sample was assessed using the same executive task battery and language background measures as the experimental sample, however, the drop-out rate was very high for the pilot sample, with only 18 participants coming back for the post-test session (14 females, mean age: 22.94, SD = 1.4). Their responses on the LHQ confirmed that participants used their L1, Spanish, to communicate 100% of the time. Assessment at pre-and post-test indicated no exposure to dual language contexts or language switching at any point, and no changes in interactional context or language use over time. Participants reported having some knowledge of an L2, English, but not actively using it in their daily lives (averaged self-assessed L2 proficiency at pre-test, M = 3.21, SE= 0.14, at post-test, M = 3.13, SE = 0.12). None of the analyses on measures of executive control revealed significant differences between the pre and post session for inhibition, F s ≤ 0.02, p >.05, η^2_p <.01, indicating that the executive performance of the pilot sample was the same at the pre-test and post-test session.

Results (experimental group)

Analyses of variance (ANOVAs). Repeated measures ANOVAs revealed a main effect of session for interference cost, F (1, 33) = 6.58, p = .02, η^2_p = .17, and a marginal effect for conflict monitoring, F (1, 33) = 3.51, p = .07, η^2_p = .10, but no significant effects for switch cost, F (1, 33) = 2.12, p >.05, η^2_p = .06, or mix cost, F (1, 33) = .03, p >.05, η^2_p <.01. Descriptive values are depicted in Figure 1.

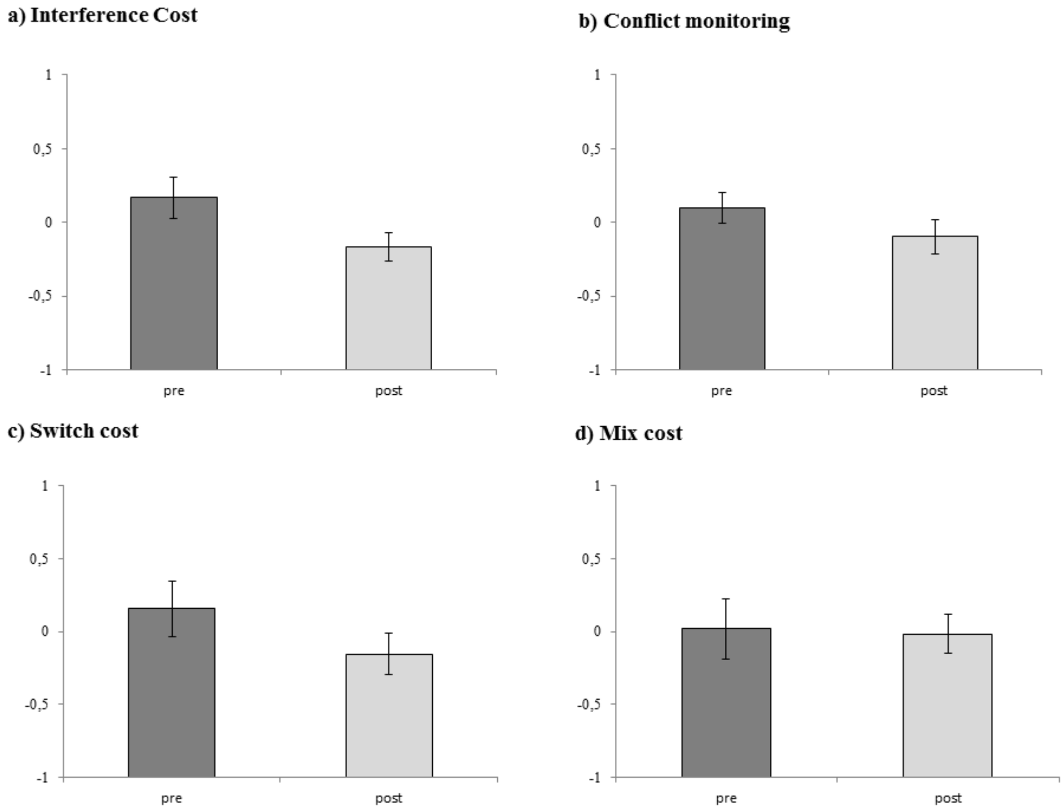

Figure 1. Graphs a-d depict average performance at pre vs. post session for switch cost, mix cost, interference cost and conflict monitoring, expressed in z-scores. Zero represents the average across pre- and post-session, negative values represent shorter reaction times/smaller cost than average, positive value longer RTs/higher cost than average.

Linear regressions. In addition to the repeated measures ANOVAS, we carried out a series of backward stepwise multiple regression analysis in order to test whether the observed change in executive performance was related to any language background measures. To that end, we calculated change scores to reflect the relative improvement in executive components observed between the pre-test and the post-test session. For interference cost, switch cost, mix cost and conflict monitoring change scores, post-test scores - where smaller scores represent better performance - were subtracted from pre-test scores. Language switching frequency, automaticity vs. control of switching, and percentage of everyday use of a language other than the L1 at post-test were entered into the analysis as predictor variables. In addition, L3 proficiency gain was entered as a control variable[16]. Results revealed that a stronger reduction in interference cost was associated with more frequent use of a non-L1 language during the immersion period (*b* = 0.18, *t* = 2.6, *p* =.01, R^2= .15), the only independent variable that reached significance and was entered into the regression model. Increased gain in conflict monitoring (stronger reduction of combined overall Flanker and Simon tasks) was predicted by the same variable (*b* = 0.16, *t* = 2.89, *p* =.007, R^2= .18). A significant predictor for reductions in switch cost and mix cost between pre and post-test was the frequency of language switching (for switch cost: *b* = 0.66, *t* = 2.14, *p* =.04, R^2= .10, mix cost, *b* = .59, *p* = .048, R^2=.09). Figure 2 illustrates the relationships between (significant) predictors and dependent variables in the regression analyses.

[16] L2 proficiency gain was not entered because the level of this variable did not increase between the pre- and the post session as did L3 proficiency.

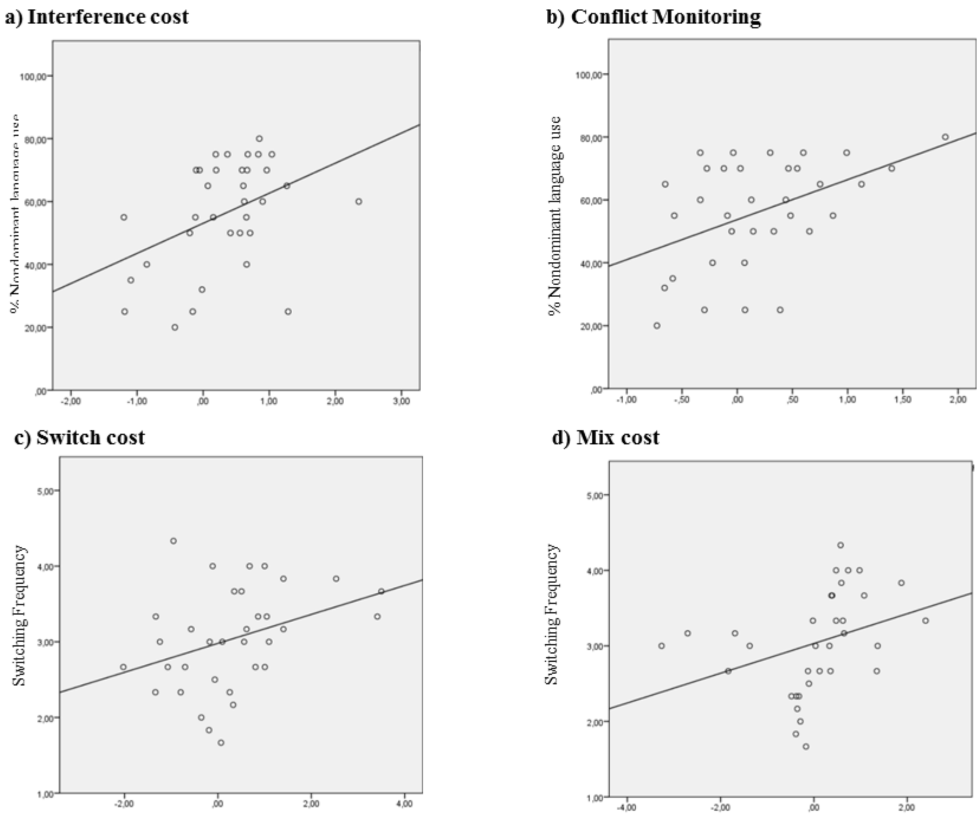

Figure 2. Graphs a and b illustrate the relationship between proportion of time communicating in a non-native, non-dominant language (combined percentage of L2 and L3 use and reduction in (a) interference cost (combined and averaged z-scores for Simon and Flanker cost) and (b) conflict monitoring (combined and averaged overall RTs for the Simon and Flanker task from pre to post session). Graphs c and d represent the relationship between overall switching frequency (on a 5-point scale) and reduction in (c) switch cost and (d) mix cost, from pre to post-session. Values are expressed in z-scores, where 0 represents the average.

Discussion

The aim of Experiment 3 was to explore whether a longitudinal change in bilingual immersion, from an almost exclusively monolingual environment, to active immersion in a non-proficient language, would lead to adaptive changes in executive performance. Our results support this hypothesis. Interference cost and, to a lesser extent, conflict monitoring, showed improvements (in terms of reductions in reaction time or interference cost) after an extended period of L3 (and L2) immersion, although this effect did not extend to measures of switch cost or mix cost. The results of the regression analysis also confirmed the role of immersion, as a larger reduction in interference cost was specifically associated with the degree of immersion: Those participants who reported using their non-dominant L2 and L3 more frequently during their stay abroad were the ones who experienced the largest reduction in interference cost. Recurrent language switching, on the other hand, appeared to be especially relevant for measures reflecting cognitive flexibility, that is, switch cost and mix cost, as revealed by regression analyses. While neither switch nor mix cost were significantly reduced from the pre to the post test session in the overall sample, these variables were predicted by the frequency of language switching during the immersion period, with those participants who reported switching between languages most frequently showing the largest reduction in switch cost and mix cost, as confirmed by regression analyses.

While the longitudinal design has a number of methodological advantages, it is also associated with some important limitations in terms of the scope of the observed effects. For example, a concern may be that the observed adaptation or training effects might be transient and only behaviorally relevant during the initial period of adaptation when processing involves more executive control (see Grant et al., 2015). In addition, participants in Experiment 3 were exposed to a very complex, unique language environment, and it is possible that our results do not generalize to other groups of immersed bilinguals. On the other hand, the pre-post comparison does not allow us to separate the effects of L2 immersion, L3 immersion, and language switching. Therefore, we decided to conduct another experiment, adopting a complementary cross-sectional approach that will allow us to compare two bilingual samples that differ selectively in their degree of L2 immersion.

Finally, we are especially interested in further elucidating the effect of language switching. Following the postulates of the adaptive control hypothesis, between-language switches may differ substantially in the degree of automaticity with which they are carried out, determining the cognitive control demands associated with switching. In Experiment 3, switching automaticity did not appear to modulate the relationship between switching frequency and enhanced flexibility reflected by switch costs or mixed costs. However, it is important to note that all of the participants in Experiment 3 were new to language switching, and likely none of them had developed true automaticity in switching. Data from bilinguals who have been immersed into their L2 for a longer time period and are not currently in the process of developing new language habits would be informative in this regard. Experiment 4 thus aimed to investigate the effects of bilingual immersion and language switching in a cross-sectional design.

Experiment 4

The main aim of Experiment 4 was to replicate previous results and extend them to a group of bilinguals who have been immersed in their non-dominant language for a longer duration, and are likely to have consolidated their language habits at the point of testing.

Methods

Participants and Procedure

Experiment 4 was conducted in State College, Pennsylvania. Participants were 25 monolingual speakers of English (12 females, mean age = 24 yrs., SD = 4.93) and 48 L2-English bilinguals who were native speakers of Mandarin Chinese or Spanish (24 females, mean age = 26.21 yrs., SD = 4.51). All of them were students of the Pennsylvania State University. The bilingual participants had learnt their L2, English, in late childhood (mean age of L2 acquisition = 9.90), and had been immersed in an L2 environment for at least 2 years. Bilinguals were relatively proficient in their L2, but the L1 was still their dominant language. Monolingual participants reported having received some formal instruction in a foreign language, but not using it in their daily lives, and not having any functional knowledge in it. Participants who had learnt a second language before the age of three, and those who had become dominant in their L2, English, were not included in the sample.

To identify bilingual groups within the sample that differed in the degree in which they actively immersed themselves in their L2, we conducted a cluster analysis based on the proportion of L2 use per day and the proportion of friends who were speakers of the L2. Two clusters of 24 bilingual speakers each emerged from this analysis. The number of Spanish-English and Chinese-English speakers in both groups was similar, with 15 vs. 16 Chinese-English, and 9 vs. 8 Spanish-English bilinguals, respectively. Both clusters differed significantly from each other in terms of their frequency of L2 use in daily life and the proportion of their friends who were speakers of the L2 (Fs $\geq$ 14.29, p < .001, $\eta_p^2 \geq .24$), but not in any other linguistic variables such as L2 proficiency, evaluated via self-assessment, a verbal fluency task, and a lexical decision task (given the cross-sectional design, two objective measures of proficiency were added in order to ensure the comparability of the two groups, see task description below), age of L2 acquisition, and language switching frequency and automaticity (all *F*s $\leq$ 1.8, p > .05, $\eta_p^2 \leq .05$). The two bilingual clusters were thus distinguished by their immersion degree; we will refer to them as *more immersed* (higher percentage of L2 use and friends) vs. *less immersed* bilinguals (lower percentage of L2 use and friends).

Monolinguals reported communicating in their L1, English, 100% of the time in their daily lives, differing significantly from both bilingual groups (*F*s $\geq$ 131.8, p < .001, $\eta_p^2 \geq .74$). In addition, they scored higher on the lexical decision task in English, their L1 and bilinguals' L2 (*F*s $\geq$ 5.52, p < .001, $\eta_p^2 \geq .74$) and lower in L2 verbal fluency as well as self-assessed L2 proficiency compared to both bilingual groups (Fs ≥ 122.44, p < .001, η_p^2 ≥ .72). Apart from the linguistic control variables, there was a marginal effect for nonverbal intelligence, assessed in terms of accuracy in the Raven Matrices (again, added to the increased need to ensure comparability between groups when using a cross-sectional design), F (2, 70) = 3.02, p = .06, η_p^2 =.08. Pairwise comparisons for this effect showed significant differences between monolinguals and both types of bilinguals, respectively (both p <.05, for monolingual vs. less immersed, and vs. more immersed bilinguals, while no differences were observed between both bilingual groups (p >.10). See Table 2 for descriptive values for each group.

Table 2.

	ML		**less immersed BL**		**more immersed BL**	
L2 Age of Acquisition	14.04	(0.48)	10.04	(0.62)	9.75	(0.75)
[a] L2 Proficiency	2.45	(0.16)	5.11	(0.18)	5.25	(0.18)
Verbal Fluency L2	0.68	(0.18)	11.33	(0.71)	12.04	(0.79)
Verbal Fluency L1	14.4	(0.69)	14.79	(0.58)	13.29	(0.61)
[b] English Proficiency	0.96	(0.01)	0.93	(0.01)	0.93	(0.01)
L2 use %	0%		45 %	(4.59)	68 %	(3.44)
L2 friends %	0%		20 %	(2.55)	66 %	(5.06)
[c] Switching Frequency	-		3.07	(0.17)	3.17	(0.21)
[c] Switching Automaticity/Control	-		2.25	(0.17)	2.03	(0.16)
Fluid intelligence	0.74	(0.02)	0.81	(0.03)	0.82	(0.03)

Note. Means and standard errors (parenthesized) for monolinguals, less immersed bilinguals and more immersed bilinguals in regards to linguistic variables and fluid intelligence. [a] Self-assessed proficiency on a 7-point scale with (1)-very poor and (7)-native-like, averaged across reading, writing, listening and speaking, 2) L1 and L2 verbal fluency, [b] Mean accuracy rate in a lexical decision task in English, [c] Assessed on a 5-point scale (for switching automaticity/control, small values represent automatic switching, large values controlled switching).

Tasks & Variables

Language questionnaires. As in Experiment 3, we used the LHQ (Li et al., 2006) and a switching questionnaire that was adapted from the BSWQ (Rodriguez-Fornells et al.,

2012) in order to assess background variables regarding language history, language switching habits, and self-assessed proficiency. The switching questionnaire was adapted for Spanish-English and Chinese-English bilingual speakers.

Verbal fluency. Participants were given semantic category names (fruit, vegetables, animals, body parts) and were asked to name as many exemplars from those categories as possible within 30 seconds. This task was done in the L1 and the L2, with the order of the languages counterbalanced, and categories rotated. Each participant was given two categories in each language. Responses were registered with a standard voice recorder and were scored by a bilingual speaker of each language pair, respectively.

Lexical decision task. Participants were presented with a list of 112 stimuli, half of which were words, while the other half were nonwords, that is, letter strings that follow orthographic and phonotactic norms in English, but are not existing words of the English language. Participants were instructed to decide whether the letter string presented on the screen was a word or not, and respond by pressing a “YES” or “NO” key on the keyboard. Stimuli were presented in black size 36 Courier New letters over a white background until participants indicated their response, they were preceded by a fixation cross in the center of the screen, and were followed by a blank screen lasting, both of which lasted 500 ms.

Nonverbal intelligence. To measure nonverbal intelligence we used Raven’s Standard Progressive Matrix task (SPM, Raven, Court, & Raven, 1988).

Executive tasks. We used the Simon task, Eriksen flanker task and Color-shape task switching paradigm as described above.

Results

As in Experiment 3, interference was measured in terms of Simon cost (RTs on incongruent trials minus RTs on congruent trials) and Flanker cost (RTs on incompatible trials minus RTs on compatible trials), conflict monitoring in terms of overall RTs on the Simon and Flanker task, switch cost as the discrepancy between switch and non-switch trials in mixed blocks of the color-shape task, and mix cost as the discrepancy between mixed and simple blocks. All measures were transformed into z-scores and mean values were calculated for composite scores (interference cost, conflict monitoring). Alpha was set to .05.

ANOVAs. There was a significant effect of the immersion group (ML vs. less immersed BL vs. more immersed BL) on interference control, F (2, 70) = 3.18, p =.048, η_p^2 = .08. Pairwise comparisons confirmed that monolinguals experienced marginally more interference cost than less immersed bilinguals (p = .07), and significantly more interference cost than more immersed bilinguals (p =.02). Between the two bilingual groups, there were no significant differences (p >.05). Analyses of conflict monitoring scores, F (2, 70) = .21, p >.05, η_p^2 <.01, switch costs, F (2, 70) = .07, p > .05, η_p^2 <.01, or mix costs, F (2, 70) = .10, p > .05, η_p^2 <.01, did not show any significant effects of immersion group. Means per group are depicted in Figure 3.

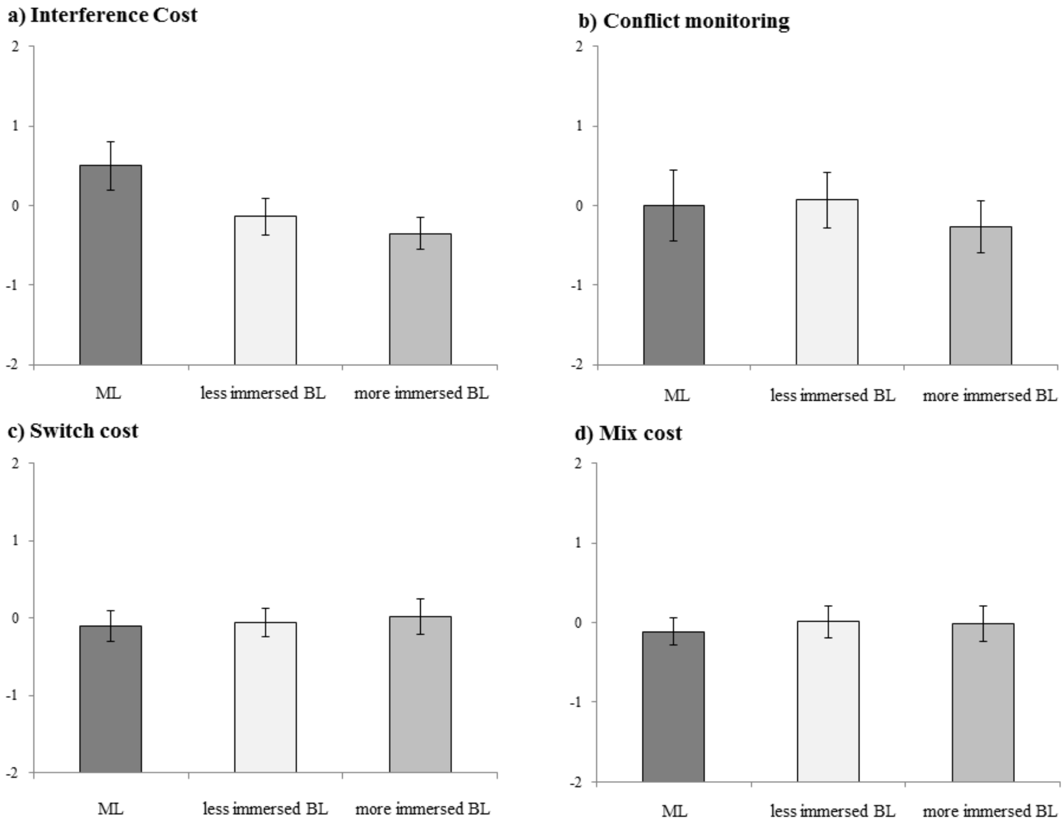

Figure 3. Graphs a-d depict average performance at pre vs. post session for switch cost, mix cost, interference cost, conflict monitoring, expressed in z-scores. Zero represents the average across pre- and post-session, negative values represent shorter reaction times/smaller cost than average, positive value longer RTs/higher cost than average.

Linear regression. Analogous to Experiment 3, we also carried out a number of backward stepwise multiple regressions in order to assess the relationship between the linguistic variables and performance on the executive tasks. In addition to language switching frequency, percentage of everyday use of a language other than the L1, and L2 proficiency, verbal fluency in the L2 was included as a predictor. Interference control was significantly predicted by L2 verbal fluency (b = -.09, t = -2.25, p =.03, R^2=.10) such that higher fluency was associated with smaller interference costs, and mix cost was significantly predicted by language switching automaticity vs. control (b = -.24, t = -2.03, p =.048, R^2 =.08), with more controlled and conscious switching being associated with smaller Mix Costs. No other predictor variables were entered into any regression model, for these dependent variables or the remaining ones, namely, Conflict Monitoring, and Switch Cost, none of which were significantly associated with any predictor. The relationships between Interference Cost and Mix Cost, and their respective predictors are depicted in Figure 4.

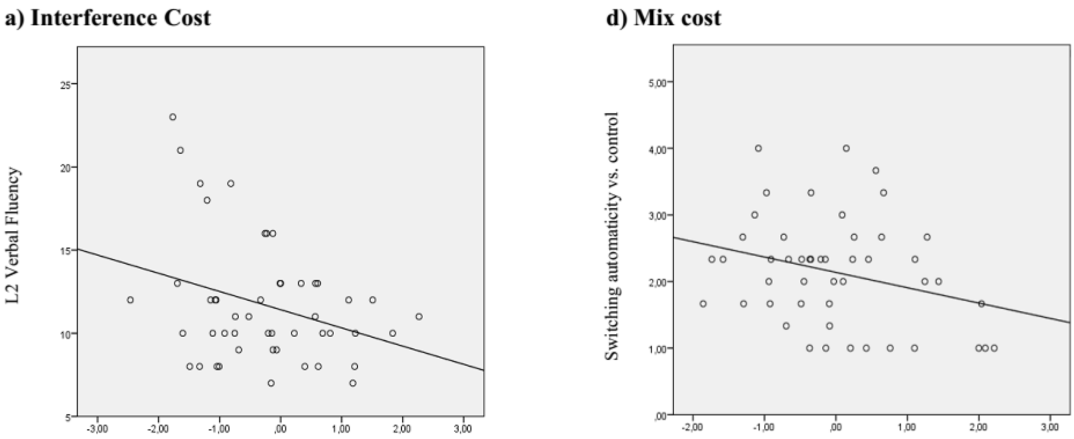

Figure 4. Graphs a) represents the linear relationship between verbal fluency in the L2 and Interference cost (combined and averaged z-scores for Simon and Flanker cost) in bilingual participants. Graph b) represents the linear relationship between language switching automaticity/control (on a scale from 1 to 5, with small values indicating automatic switching and large values indicating controlled switching) and Mix Cost (expressed in z-scores, where 0 represents the mean).

Discussion

The results of Experiment 4 corroborate the crucial role of L2 immersion in producing an executive advantage in bilingual relative to monolingual speakers. We observed an overall effect of immersion group (monolingual/no immersion, less immersion, more immersion) on interference control that was stronger for the more immersed relative to the less immersed bilinguals, who showed only a marginal difference from monolinguals. This finding aligns with the enhanced inhibitory control observed in Experiment 3 after a period of L2/L3 immersion. None of the other measures of executive functioning, namely, conflict monitoring, switch cost or mix cost proved to be influenced by immersion in the same way; which is only partly in line with the results of Experiment 3. In terms of the other language variables, regression analyses reveal an effect of language switching automaticity (control over switches), but not switching frequency per se, on mix cost, while L2 fluency appeared to be related to interference control.

General Discussion

Recent literature has argued for a refined version of the bilingual executive control hypothesis to account for the conditions under which bilingualism leads to enhanced executive control. The present study contributes to this issue both conceptually and methodologically. Our aim was to elucidate the modulatory role of two factors – the degree of active L2 immersion and language switching habits, on the effect of bilingualism on executive control. Regarding immersion in a non-dominant language, the results of both experiments speak in favor of an effect on interference control and to a lesser degree, on conflict monitoring. In Experiment 3, we observed an effect of session (pre vs. post) on interference control for the entire sample, with a larger reduction in interference cost for those participants who reported using their non-dominant languages most frequently during the immersion period, while Experiment 4 demonstrated smaller interference costs for those bilinguals who immersed themselves more in their second and less dominant language rather than their L1. For conflict monitoring, the effect of session was marginal and the degree of immersion in the non-dominant language predicted improvement in this mechanism in Experiment 3, but there were no significant effects involving conflict monitoring in Experiment 4. Generally speaking, these data are in line with previous evidence for enhanced inhibitory control in young adult late bilinguals (Bak, Vega-Mendoza, & Sorace, 2014, Tao, Marzecóva, Taft, Asanowicz, & Wodniecka, 2011, Vega-

Mendoza et al., 2015, Verreyt et al., 2016) and add further longitudinal evidence that L2 practice or "becoming more bilingual" can lead to adaptively enhanced cognitive control (Mcnamara & Conway, 2014, Nicolay & Poncelet, 2015, see also Mårtensson & Lövdén, 2011). At the same time, our findings are consistent with the hypothesis that not all bilinguals show executive advantages, and that it is the cumulative experience with complex and dynamic linguistic environments that leads to enhanced behavioral performance over time (Green & Abutalebi, 2013, Mcnamara & Conway, 2014).

In terms of distinct executive functions, the data from our sample suggest that enhanced interference control is more prevalent in bilinguals than superior performance on task switching paradigms. Previous studies concur that interference control is more susceptible to adaptive effects due to bilingualism or L2 acquisition than set shifting (Vega-Mendoza et al., 2015), and that reduced switch costs or mix costs may be selective to bilinguals who frequently switch between languages (Prior & Gollan, 2011, Soveri et al., 2011). The dissociation of interference control and set shifting is also plausible on the basis of the adaptive control hypothesis (Green & Abutalebi, 2013), which makes different predictions for mechanisms that stabilize a current task setting (such as inhibition) and mechanisms that enable flexible change between distinct task settings, respectively. This is in line with the results of the regression analyses in Experiment 3, where frequent switching between languages during the immersion period was associated with a reduction in switch cost and mix cost.

Interestingly, in Experiment 4 task switching performance was not associated with switching frequency, but to the automaticity of switching. Bilinguals in the second experiment had been immersed in their linguistic environment for a longer duration (i.e., several years). They had developed and established language habits over this time and unlike the participants in Experiment 3, had had a chance to develop a high degree in automaticity in language switching. Although there was variation in switching frequency within this group, all bilinguals in Experiment 4 reported engaging in language switching to some extent in their daily lives, and frequency differences were not related to any of the executive variables. However, the degree of controlled rather than automatic or involuntary switching predicted mix costs, with individuals who reported greater control over language switches exhibiting smaller mix costs. In line with this latter finding, Festman and colleagues (Festman, Rodriguez-Fornells, & Münte, 2010, Festman, 2012) found that bilinguals who are not able to exert control over language switches and frequently experience involuntary switches also show less efficient domain-general executive control and cognitive flexibility. Similarly, a recent study by Hartanto and Yang (2016) showed that inter-sentential and extra-sentential code-switching predicted switch costs in opposite directions. More specifically, extrasentential code-switching predicted reduced switch costs, while intra-sentential switching predicted increased switch costs. The authors interpreted this finding to suggest that the two types of switching impose different control demands on the executive system, with the cognitive load associated with language set reconfiguration being reduced in the case of automatic intra-sentential switches reducing (see also Gollan, Kleinman, & Wierenga, 2014). Thus, evidence suggests that there may be different types of language switches: intrusions from the stronger language, code switching in highly balanced environments, and externally paced switches in response to recurrent changes of the target language might all be perceived as language switching by participants and may be reported as such in commonly used language questionnaires. However, predictions regarding their executive control demands differ (Festman, Rodriguez-Fornells & Münte, 2010, Green & Abutalebi, 2013). The results of the two experiments illustrate this point, suggesting that the relationship between language switching and (flexible) executive control may be modulated by the degree of automaticity vs. control over language switches. Thus, the effects of switching frequency observed for new language switchers in Experiment 3 do not hold for the sample of Experiment 4, comprised of bilinguals who, by the time of testing, had established their language habits for a long period of time. Instead, Experiment 4 showed an effect of control vs. automaticity of language switches, with more controlled switching predicting increased flexibility. Once more, this pattern appears to be in line with the predictions of Green and Abutalebi (2013), whereby externally cued target language changes, but not internally paced automatic switches are associated with increased control demands. However, further studies are needed and should ideally include objective measures of language switching or changing. These studies should also address how long the duration of the immersion period (or training intervention) has to be in order to produce measurable behavioral effects (see Prior & Gollan, 2013, Mcnamara & Conway, 2014, Mårtensson & Lövdén, 2010).

Overall, the observation of selective effects for different executive functions depending on certain aspects of the bilingual experience - immersion and switching - supports the idea that the emergence of adaptive executive advantages is constrained by the way executive control is exercised during bilinguals' daily interactions. In addition, this study makes an important methodological contribution by combining longitudinal, cross-sectional, and correlational research methods, all of which are associated with specific advantages and shortcomings. For example, some researchers have voiced concerns that between-group differences in cross-sectional designs may be caused by hidden demographic factors like socioeconomic status (SES), ethnicity, or immigrant status, rather than language status (Morton & Harper, 2007, Paap & Greenberg, 2013). This problem can be circumvented by means of longitudinal designs where participants serve as their own baseline. On the other hand, individual contributions of different factors associated with bilingualism are more difficult to assess longitudinally. The overall effect of session (Experiment 3) represents the summative impact of increased L2 and L3 use, increase in L3 (and to some degree, L2) proficiency, and exposure to an immensely complex mixed language environment that requires frequent switching between up to three target languages. Here, the cross-sectional design (Experiment 4) allows for a more clear-cut comparison as the two bilingual groups differ in the degree of immersion in their L2, while other linguistic variables including proficiency and switching frequency are balanced between groups. Multiple regression analyses additionally contribute to understanding the individual contributions of distinct variables. Nevertheless, it is important to note that in the present study, the contributions of L2 immersion vs. language switching can only be dissociated to a certain degree.

Although our results are generally consistent with a refined version of the bilingual executive advantage account, more research is needed to define its boundary conditions. For example, it has been suggested that a bilingual executive function advantage in mechanisms of interference control (i.e., inhibition or conflict monitoring) depends on the experience of interlanguage conflict and will not emerge in bilinguals immersed in dense code switching environments (Green & Abutalebi, 2013). Our results are compatible with a the idea that interlanguage conflict is key to the emergence of bilingual executive advantages, but do not test this assumption directly, and do not preclude that adaptive effects may occur in the absence of conflict in other bilingual populations.

Conclusion

To sum up, the present research confirms the role of active L2 immersion in the emergence of a measurable executive function advantage. The two experiments reported here provide complementary evidence for this conclusion. In conjunction with other studies, this research contributes to understanding the different facets of the cognitive consequences of bilingualism, especially why some, but not all, bilinguals might exhibit an executive function advantage, and why some, but not all, aspects of executive functioning may be subject to a selective advantage in certain bilingual populations. The overall body of data at this point seems to suggest that the interaction between bilingualism and executive control may be far more complex than previously assumed. Rather than referring to *the* bilingual executive advantage, it might be useful to assume a range of distinct, but related effects. Still, there are many open questions in terms of the necessary conditions and limitations of the observed effect(s), which should be addressed by future research. Despite of these limitations and concerns, we hope that our research may contribute to understanding the conditions under which multiple language use may lead to adaptive cognitive change.

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Experimental Series III (Experiment 5)

Experiment 5. How native-like can you get? The role of L2 proficiency and cognitive control in L1 and L2 text-level processing

The present study compares semantic processing at the text level in late bilinguals' first and second language. At this level, semantic access and integration depend on higher-level processes such as inference making and revision. Twenty-four young adult bilinguals with a high level of proficiency in their L2 were presented with short narrative texts in English (L1) and Spanish (L2) that prompt participants to infer specific information from text and subsequently revise this initial inference. Inference generation and, in particular, inferential revision were less efficient in the L2 compared to the L1, as suggested by behavioral data as well as N400 effects. In addition, individual differences in L2 proficiency and cognitive control modulated high-level reading processes in both languages. Higher L2 proficiency and a strong tendency towards proactive control were associated with more native-like processing in the L2. In contrast, in the L1, more efficient revision was predicted by a balanced reliance on reactive and proactive control, and higher L2 proficiency was associated with less efficient revision. Thus, high-level reading processes are less efficient in the L2 compared to the L1, and both languages tax cognitive control in different, characteristic ways. Processing differences between languages become smaller with higher L2 proficiency and a stronger tendency towards proactive control.

Mastering a non-native language can be very challenging, especially if this second language has been acquired relatively late in life. Nevertheless, even adult learners can reach high levels of proficiency in their L2, and with increasing proficiency many aspects of L2 processing can become more and more native-like (see Birdsong, 2001). It is generally assumed that one area where L2 processing can become relatively close to native-like is semantic comprehension (for reviews, see Clahsen & Felser, 2006, Frenck-Mestre, 2005, Mueller, 2005, Slabakova, 2006). On the lexical level, L1 and L2 share the same semantic network, and at least in proficient bilinguals, access to this network is direct, automatic, and unmediated in both languages (Dufour & Kroll, 1995, Duyck & De Houwer, 2008, Kroll & Stewart, 1994, Scherag, Demuth, Rösler, Neville, & Röder, 2004). At the sentence level, second language comprehenders are able to detect semantic violations behaviorally and they seem to engage the same neuroanatomic structures in the L1 and L2 to do so (Wartenburger, Heekeren, Abutalebi, Cappa, Villringer, & Perani, 2003).

A sensitive marker of semantic processing that is often used to study sentence comprehension is the N400 component (Kutas & Hillyard, 1980), a negative inflection of the EEG signal that is observed following the presentation of a stimulus (e.g., a word) embedded in a context (e.g., a sentence). Its amplitude reflects the ease with which the meaning of a word can be integrated into the current mental representation. Thus, N400 effects (i.e., amplitude differences between experimental conditions) are observed for words that are unexpected vs. expected in a given context (e.g., “It was raining so he grabbed his… *coat/umbrella*”, respectively). Late bilinguals also show N400 effects for target words that are semantically inconsistent (e.g., Ardal, Donald, Meuter, Muldrew, & Luce, 1990, Newman & Tremblay, 2012, Ojima, Nakata, & Kakigi, 2005), are nonwords (Sanders & Neville, 2003), or are unexpected within highly constrained sentences (Martin, Thierry, Kuipers, Boutonnet, Foucart, & Costa, 2013) when processing sentences in their L2. However, compared to the L1 these effects are often delayed or reduced in amplitude in the

L2 (Newman & Tremblay, 2012, Martin et al., 2013, Meuter et al., 1987, Ardal et al., 1990, Weber-Fox & Neville, 1996). In addition, according to more recent accounts, N400 effects not only reflects (passive) integration processes but also active prediction of to-be-expected information, and there is evidence that L2 comprehenders are less likely to predict upcoming information even when integration processes in the L2 are native-like (Martin et al., 2013, but see Foucart, Martin, Moreno, & Costa, 2014). The processing differences reflected by reduced N400 effects appear to be determined by proficiency even in the L1 (Newman & Tremblay, 2012), and revert in participants whose L2 has become their more dominant language (Moreno & Kutas, 2005). Thus, although semantic processing is not fundamentally different in a non-native language acquired late in life compared to a native language, some residual differences may remain that seem to be mainly quantitative in nature.

Importantly, the current body of data is limited to the level of individual words or sentences, and does not reflect the complexity of language comprehension in real life. Text-level comprehension is more representative of real-life processing. Many processes are similar in sentence- and text level processing, but differ in complexity: like sentence comprehension, text comprehension requires the construction of a mental representation (referred to as situation model, van Dijk & Kintsch, 1983) and subsequent integration of new information. On the other hand, semantic access and semantic integration at the text-level depend on multiple higher-order processes that are not present at lower processing levels. For example, a crucial aspect of text comprehension is the ability to generate information that has not been explicitly described, referred to as inference making (e.g., Cain & Oakhill, 1999). In order to construct an accurate and coherent situation model, readers must connect several pieces of information presented in the text and/or activate prior knowledge from long-term memory (see McNamara & Magliano, 2009). Such knowledge-based inferences tend to be generated automatically in proficient readers

(McKoon & Ratcliff, 1980). Inference making is an ongoing process: as the text unfolds, initial inferences can become outdated, in which case they have to be replaced with newly generated inferences (see Pérez, Joseph, Bajo, & Nation, in press). Integrity and efficiency of inference generation and revision are requisite for successful text comprehension (e.g., Zwaan, Langston, & Graesser, 1995).

Research into these high-level reading skills in the L2 is scarce. Preliminary evidence suggests that readers with advanced L2 proficiency generate the same amount of elaborative inferences in their L1 and L2 (Horiba, 1996) and with increased proficiency, L2 readers show more efficient revision compared to less proficient readers (e.g., Yang, 2002). However, no previous study has directly compared inferential revision in L2 and L1, and processes such as text-level inference making and sentence-level integration have only been studied in isolation, although critical differences between native and non-native processing may also lie in their dynamic interaction. In sum, it is currently unclear to what extent findings regarding non-native semantic processing at the level of individual words or sentences extend to higher levels of linguistic complexity, especially when demands for complex processes such as the generation and revision of inferences are high. Therefore, the main aim of this study is to investigate these processes in late bilinguals' L1 and L2.

Previous evidence across processing levels suggests that most of the processing differences due to language status can be explained in terms of linguistic proficiency (see Newman & Tremblay, 2012, Kaan, 2014, Horiba, 1996, Yang, 2002). However, some of the difficulties with high-level processes in less proficient L2 speakers could be explained in terms of a capacity deficit: as less proficient readers need to allocate more cognitive resources to lower level processes (e.g., lexical processing), less resources are available for higher level, conceptual processes (Horiba, 1996, Yang, 2002, see also Horiba & Fukaya, 2015). Non-native language processing requires more working memory resources (e.g., Dussias & Pinar, 2010, Ransdell, Arecco, & Levy, 2001) and even simple linguistic processes such as lexical access increase activation in brain areas associated with cognitive control (Ma et al., 2014). Consequentially, although previous research has largely neglected the role of nonlinguistic factors, it seems likely that domain-general cognitive resources may be another important source of individual variation in L2 semantic processing. In monolinguals, individual differences in cognitive control, including working memory and inhibition, explain variance in reading comprehension above and beyond linguistic variables (e.g., Arrington, Kulesz, Francis, Fletcher, & Barnes, 2014, Borella, Caretti, & Pelegrino, 2011, Borella, Ghisletta, & Ribaupierre, 2011), and the same is true for inferential revision in particular (Pérez et al., 2015). Therefore, there is reason to believe that cognitive control resources may interact with linguistic proficiency in predicting text-level L2 comprehension. A second aim of this study is to explore the role of individual differences in both L2 proficiency and cognitive control in text-level semantic processes in the L1 and L2.

The present study

A paradigm that was developed precisely to investigate the interaction between inference, integration and revision processes is the situation model revision task (Pérez, Cain, Castellanos, & Bajo, 2015). In this task, participants are presented with short narrative texts (see Table 1 for an example). Each text contains an introduction (sentences 1-3) that facilitates an inference (e.g., '*fight*'). The experimental manipulation is implemented in the following sentence (sentence 4) where readers are presented with one of three conditions: a neutral condition, which does not refer back to the inference (e.g., '*...older with slightly greying hair'*); a non-update condition, which is consistent with the inference primed in the introduction (e.g., '*...more and more aggressive'*); and an update condition, which mismatches the inference primed in the introduction and facilitates the generation of a new inference (e.g., '*…very convincing in their roles'*). Thus, this latter condition primes the replacement of the previous inference with a new one (revision). Reading times are measured for sentence 4.

Table 1. Example of text used in the situation model revision task.

Introduction The tension between the two men was high. One of them took advantage and smacked the other straight on the jaw. The people watching could not believe what they were seeing.		(bias *fight*)
Sentence 4 (RT) One of the men was *older with slightly greying hair*. The men became *more and more aggressive*. The actors were *very convincing in their roles*.		Neutral Non-update Update
Sentence 5 (ERP) That moment was the most violent of the **play**.	(coming from *'hair'*) (coming from *'aggressive'*) (coming from *'roles'*)	Neutral Non-updated Updated
Comprehension sentence One man smacked the other on the leg.		

Note. Bilinguals saw the text in the neutral/neutral, non-update/non-updated or update/updated condition, in the L1 or the L2.

The final sentence (sentence 5) always presents a disambiguating word (e.g., '*play*'), that is inconsistent with the inference primed in the introduction ('*fight*'), but consistent with the new inference facilitated in the update condition ('*roles*'). Note that the status of the disambiguating word in sentence 5 as expected vs. unexpected depends on the condition presented in the previous sentence 4. We will refer to the sentence-5 condition as "updated" when coming from the "update" condition, as "non-updated" when coming from the "non-update" condition, and as "neutral" when coming from the "neutral" condition in the previous sentence 4.

In line with the literature discussed above, we will consider reading times as well as ERP measures. First, sentence 4 reading times allow us to draw conclusions about inference generation during the introduction. Increased sentence 4 reading times for the update (i.e., '*roles*' when coming from *'fight'*) compared to the non-update (i.e., '*aggressive*' when coming from *'fight'*) and the neutral (i.e., '*hair*' when coming from *'fight'*) indicate that readers were able to infer the concept facilitated in the introduction. Secondly, amplitudes of the N400 component elicited by the disambiguating word at the end of sentence 5 inform us about the processing cost of integrating this word (e.g., '*play*') in the current mental representation, the situation model. Therefore, N400 effects tell us whether participants were able to revise initial inferences. Reduced N400 amplitudes elicited by the disambiguating sentence 5 word in the updated condition (i.e., '*play*' when coming from *'roles'*) compared to the non-updated (i.e., '*play*' when coming from *'aggressive'*) and neutral (i.e., '*play*' when coming from *'hair'*) condition indicate that participants were able to take advantage of the new information given in the sentence 4 update condition to successfully revise their situation model.

Individual differences in cognitive control will be assessed in terms of the reactive/proactive framework of cognitive control (Braver, 2012). This framework distinguishes between two different types of cognitive control. Proactive control is implemented pre-emptively, by sustained goal maintenance and anticipatory monitoring throughout performance of a cognitive task. Attentional and perceptual processes are biased towards goal-relevant information. Reactive control, on the other hand, consists in the momentary and transient activation of the task goal in the light of conflict or interference. Since reactive control is resource-economic, it is usually exerted when cognitive resources are limited either due to individual capacity limits or when the task demands are particularly high. Proactive control is highly dependent on the availability of Working Memory capacity (Braver, 2012), whereas reactive control has been associated with inhibition, both empirically and theoretically (Morales et al., 2013). Both types of cognitive control are likely to contribute to the high-level reading skills studied here (see predictions below).

Based on previous literature, we predict text-level inference generation and revision to be less efficient in the L2 compared to the L1, and we expected processing differences to be more pronounced for inferential revision as it is particularly resource demanding (see

Pérez et al., 2015). Furthermore, behavioral and electrophysiological should be modulated by individual differences in both L2 proficiency and cognitive control. We expect processing differences due to language status to be attenuated in readers with high L2 proficiency, so that text-level inference and revision will be more native-like in more proficient L2 readers (see, e.g., Horiba & Fukaya, 2015, Yang, 2002). In regards to cognitive control, we expect to observe modulatory effects in both the L1 and L2. Very few previous studies have explored the effect of cognitive control on linguistic processes in terms of the reactive/proactive taxonomy. However, we tentatively predict that inference making and revision may be supported by the interplay of different control modes. Inference generation requires the connection of information in the text and in long-term memory, an operation that likely relies on working memory, and maintenance of a strong task set (here, the situation model). We thus hypothesize that inference making is supported by proactive cognitive control. Revising inferences requires overriding a previous, alternative interpretation of the available information a process that has been argued to involve inhibition (see Pérez et al., 2015). Thus, we assume that revision might rely most critically on reactive control processes. Finally, we anticipate that L2 readers with better-suited cognitive control abilities might be able to engage high-level processes in a more native-like fashion, yielding a larger effect on the L2 compared to the L1 (for a similar proposal regarding less proficient L1 readers, see Denckla, 1993).

Method

Participants

Participants were 24 native speakers of English (15 females, 9 males, Age: *M* = 28.58, *SE* = 1.25) who were proficient in Spanish, their L2. All participants had learned Spanish after the age of 11 (*M* = 17.21, *SE* = 0.63), and at the time of testing, had been living in a Spanish speaking country for a minimum of one year (*M* = 4.05, *SD* = 1.11).

Participants gave their informed consent prior to testing and received a monetary compensation (12-16€ depending on the duration of the session) for their participation.

Materials

Our materials are divided in three different sections: a) language background and cognitive control measures, b) individual differences indices and c) reading comprehension task. First, a series of measures were employed to assess cognitive control as well as different aspects of participants' language background and ensure they had a high level of L2 proficiency (approximating native-likeness; see Table 2). Secondly, we extracted two different predictor indices from these measures to evalute the contribution of individual differences in 1) L2 proficiency and 2) cognitive control to high-level reading skills. Finally, the situation model revision task was used to measure revision and integration in reading comprehension.

Language background and cognitive control measures

Language questionnaires. Adapted versions of the Language History Questionnaire (LHQ, Li, Sepanski, & Zhao, 2006) and the Bilingual Switching Questionnaire (BSWQ, Rodriguez-Fornells, Krämer, Lorenzo-Seva, Festman, & Münte, 2012) were used to measure language background, self-assessed L2 abilities in reading, writing, speaking and listening, language use and frequency of exposure to multilingual contexts as well as language switching habits.

Vocabulary test and comprehension questionnaire. A vocabulary test was created comprising critical words from the situation model revision task. This test served to both measure participants' L2 proficiency and identify any words in the situation model revision task that participants may not understand. Words on the list were presented individually in Spanish (the L2) in the center of a computer screen in randomized order, and participants were asked to translate them into English (the L1) by typing their response on a blank screen. Participants were given as much time as needed to respond and, in case they did not know the correct translation of a word, were asked to make a guess or try to deduce the meaning. To proceed to the next trial, participants once again had to press a key. Two versions of this list were created to coincide with the counterbalance version of the situation model revision task. The accuracy proportion was calculated for each participant to yield individual vocabulary scores (*M* = 87%, *SE* = 2%).

Previous to session 2, a customized paper and pencil vocabulary test was prepared, containing any remaining vocabulary participants had not been able to correctly translate on the session 1 vocabulary test, to be completed after the situation model revision task. On this post-session test, critical words were presented within a sentence (taken from the situation model revision task). If there were any critical words participants failed to correctly translate the second time and when given the context, the corresponding texts were excluded from all subsequent analysis for the participant in question. In addition, participants were asked to assess the perceived difficulty of the texts, to be indicated on a 5-point scale (1-very easy, 2-easy, 3-intermediate, 4-difficult, 5-very difficult). The average score for perceived difficulty was 2.20 (*SD* = 0.17), indicating that participants found the texts easy to understand.

Verbal fluency. Participants were given a category name (e.g., "*animals*"), and had to name exemplars from this category. There were two blocks: a Spanish one and an English one. Participants were given 30 seconds to name as many exemplars from the current category as possible. Once the 30 seconds were up, participants once again heard a tone, and the word "STOP" appeared on the screen for 1500ms. The order of presentation of the blocks was counterbalanced across participants. Participants were given one practice category at the beginning of the task. Two categories were tested per block, rotating across participants so that each category was presented in the Spanish and English block to an equal number of participants. Verbal fluency scores in Spanish and English were calculated as the average number of correctly named category exemplars for the corresponding block.

Verbal Working Memory (WM). We used an operational span task identical to the one described by Morales, Gómez-Ariza, and Bajo (2015), where trials consist in the presentation of an arithmetical equation that may be either correct or incorrect, followed by a single word. Participants were instructed to solve the equations and indicate whether or not they were correct by pressing a “Yes” or a “No” button, and memorize the subsequently presented words. Trials were organized into sets of varying size. Each set ended in a recall phase, where participants were asked to recall the words that were presented in the current set. Set size ranged from 2 to 6, and after 3 sets of the same size, set size increased. There were two task blocks, a Spanish and an English one, with 15 sets each. The order of presentation of the blocks was counterbalanced across participants. To calculate Spanish and English verbal WM scores, we summed up all the correctly recalled words across the respective blocks. A recalled word was not added to the sum if the corresponding equation it had not been solved correctly, or if the word was the last one presented in a set but was typed first during the recall phase.

Table 2. Descriptive values for variables related to L2 vs. L1 proficiency and use.

a) L2 proficiency

Reading	5.52	(0.15)
Writing	4.96	(0.19)
Speaking	5.54	(0.17)
Listening	5.59	(0.17)
Total	**5.40**	**(0.14)**

b) Language exposure and language control

	L1-English		L2-Spanish	
Daily use (in %)	52.83	(4.51)	46.67	(4.37)
Friends (in %)	50.08	(6.69)	49.92	(6.69)
Verbal fluency	13.56	(0.58)	12.40	(0.73)
Verbal WM	30.56	(2.17)	26.89	(2.48)

Note. (a) Self-assessment of L2 abilities on a 7-point scale with (1) - very poor, (2) - poor, (3) - fair, (4) - neutral, (5) - good, (6) - very good, (7) - native-like). (b) Variables related to language exposure (proportion of daily language use, as well as friends who are speakers of a language) and language control (verbal fluency and verbal WM) in L1-English and L2-Spanish, respectively. Differences between L1 and L2 were non-significant (all Fs $(1, 23) \leq 1.76$, ps $> .05$).

Cognitive control. To measure cognitive control, we used the AX-Continuous Performance Task (AX-CPT) as described by Morales and colleagues (2013). Participants saw red and white capital letters presented over a black background. A trial consisted in a sequence of five letters, a red cue letter, 3 white distractor letters, followed by a red target letter. Participants were instructed to respond to the final target letter by pressing one of two keys. Specifically, they were to press a “Yes” key only if the target letter was the letter “X”, and if the preceding cue had been the letter “A” (AX-trials). In any other case, they were to respond by pressing a “No” key. In addition, participants were asked to always press the designated “No” key in response to each of the white letters presented between cue and target. The task comprised 100 trials, 70% of which where AX-trials. The other trials could comprise a valid cue (A) but invalid target (any other letter than X; AY-trials), an invalid cue (any letter other than A) followed by a valid target (X; BX-trials) or an invalid cue followed by an invalid target (BY-trials), each of which ocurred 10% of the time. Cue letters appeared on the screen for a duration of 300ms, distractors and target letters for a duration of 300ms or until participants pressed the “Yes” or “No” key. Between each letter and at the end of a trial a blank screen appeared for the duration of 1000ms. Preceding experimental trials, there was a practice phase comprising 10 trials (seven AX-trials, one AY-trial, BX-trial and BY-trial each), during which participants received a feedback regarding speed and accuracy of their response at the end of each trial. High error rates in the BX-condition reflect reliance on reactive control and/or absence of proactive control, whereas high error rates in the AY- condition reflect reliance on proactive control and/or failure to engage reactive control. Due to the large percentage of AY-trials, this version of the task prompts predominant reliance on proactive control.

Individual difference indices

From the language background and cognitive control tasks described above, we calculated two indices: 1) L2 proficiency, and 2) cognitive control, to be entered as individual differences variables in the upcoming analysis of the situation model revision task.

L2 proficiency. To create a single, valid and comprehensive measure of L2-Spanish proficiency, we carried out a Principal Component Analyses (PCA) on three variables: mean scores for L2 reading, writing, speaking and listening on the self-evaluation scale, session 1 vocabulary scores, and verbal fluency in Spanish divided by English fluency, to account for individual differences in baseline fluency. Only one principal component with an eigenvalue of > 1.0 emerged (visual inspection of the scree plot confirmed the number of components), accounting for 62.03% of overall variance. Preliminary testing revealed a Kaiser-Meyer-Olkin (KMO) value of .51, and significance of Bartlett's test for sphericity (p = .001), justifying the use of PCA. Factor loadings were .59 for L2 verbal fluency, .82 for mean L2 ability according to self-assessment, and .91 for vocabulary. The resulting factor scores, representing variance shared by the three base variables, were extracted and were submitted to LMMs (see below) as proficiency scores.

Cognitive control: Behavioral Shift Index (BSI). To measure individual tendencies towards proactive vs. reactive control, we calculated the Behavioral Shift Index (BSI, Braver, Paxton, Locke, & Barch, 2009). The BSI is based on the formula (AY-BX)/(AY+BX), computed for errors, reaction times and then averaged. Trials where errors were equal to 0 were corrected as [(errors + 0.5)/ frequency of trials + 1]. Larger BSIs (above 0) indicate a preference for tendency towards proactive control, whereas smaller BSIs (below 0) indicate a tendency towards reactive control. It is important to note, however, the distribution of our sample in regards to properly interpret individual BSI scores. In general, this version of the AX-CPT is designed to reinforce proactive control strategies: proactive control leads to a high success rate, although at the expense of trials that require reactive control. Young healthy adults do not typically show a strong preference for reactive control, and accordingly, BSI scores in our sample accumulate in the "proactive range" from around 0 to 1 with very few negative scores at all. Therefore, a high BSI *within our sample* reflects a strong tendency towards proactive control whereas a lower BSI reflects more balanced reliance on proactive and reactive control.

Reading comprehension

Situation model revision task. We used the paradigm developed by Pérez et al. (2015). To assess performance in both languages, all texts were translated from English to Spanish. Each participant was presented with a total amount of 90 (45 English and 45 Spanish) experimental texts that were five sentences long each (see Table 1), in addition to three practice texts at the beginning of each language block. In each text, sentences 1-3 (introduction) biased an inference (e.g., '*fight*'). Then, sentence 4 could bring a) information not related to the previous interpretation (neutral), b) inferential information consistent with the previous interpretation (e.g., '*...more and more aggressive';* non-update), and c) new inferential information that mismatched the previous interpretation and facilitated the generation of a new inference (e.g., '*…very convincing in their roles'*; update). Reading times (in milliseconds) were measured for this sentence. Finally, sentence 5 ended in a disambiguating word (e.g., '*play*'), which was always inconsistent with the inference biased in the introduction and consistent with the interpretation supported by sentence 4 in the update condition. Consequently, the disambiguating word was unexpected in the neutral and the non-updated condition, and expected in the updated condition. ERPs were recorded at the onset of the disambiguating word (sentence 5). At the end of each text, a comprehension sentence requiring a true or false judgment was presented to ensure that participants read for understanding.

Procedure

There were two experimental sessions. Participants who volunteered for participation were contacted per E-Mail or telephone and asked a few screening questions to ensure whether they met minimum requirements. Only those participants who had lived in a Spanish-speaking country for at least a year, had learned their L2 after the age of 10 and judged themselves to have a higher level of proficiency were invited to the first session. In this session, participants completed all behavioral tasks (operational span in L1 and L2, verbal fluency, and AX-CPT) and language questionnaires (LHQ, BSWQ). Only participants who reached an accuracy cut-off of 60% on the original vocabulary test were invited to the second experimental session.

In the second session, EEG recordings took place while participants carried out the situation model revision task (approx. 90 minutes). This task was administered in two blocks, one in English and the other in Spanish. Each trial started with a fixation cross ('+') that remained on the screen until the participant pressed the "Yes"' or "No" key on the keyboard to start reading. Sentences 1–4 were presented one sentence at a time, and participants were asked to read each sentence at their own pace, pressing the same key to display the next sentence. Reading times for sentence 4 were registered. Subsequently, sentence 5 was presented word by word with a fixed duration of 300ms per word. In addition, there was a delay of 700ms after the disambiguating word to ensure the recording of activity during a sufficiently long time window. Participants were instructed to try not to blink during sentence 5, in order to prevent excessive noise in the EEG data. Finally, a comprehension sentence was presented, and participants were instructed to press the "Yes" key, if they thought the sentence was true, or "No" if they thought it was false. Each of the

90 experimental texts was presented to each participant only once, in one of the two languages and the three conditions. The same number of participants completed the six cross conditions The assignment of language and condition to text was counterbalanced across participants, so that each participant read 15 texts within each factor level combination of condition and language. The order of language block was also counterbalanced. A practice of three trials ensured that instructions were understood. In addition, at the end of the second session, participants were also asked to complete the post-session vocabulary task (5-10 minutes).

Apparatus

Tasks were presented by the E-prime software (Schneider, Eschman, & Zuccolotto, 2002), administered on a 19" in. CRT video monitor (refresh rate = 75 Hz). For the situation model revision task, we recorded scalp voltages using a SynAmps2 64 channels Quik-Cap, plugged into a Neuroscan SynAmps RT amplifier. The electrical signal was amplified with a 1– 30 Hz band-pass filter and a continuous sample rate of 250 Hz. The vertical and horizontal electrooculogram was registered supra- and infraorbitally to the left eye and at the outer canthi. Impedances were kept below 5 kΩ. Blinks and other ocular movements were corrected. Trials with artifacts (3.12%) were rejected and recordings from electrodes with high level of artifacts (> 1%), were substituted by the average value of the group of nearest electrodes. Epochs from -200 and 800ms with respect to the presentation of the disambiguating word were averaged and analyzed. We applied baseline correction, using the average EEG activity in the 200ms previous to target onset as a reference. ERPs were averaged for each factor level combination by participant, text, and region of interest. Individual averages were re-referenced off-line to the average of left and right mastoids.

Data analysis

Reading times**.** Reading times (RTs) were measured for sentence 4 of the texts presented in the situation model revision task. To factor out differences between L1 and L2 in baseline reading speed, we divided RTs for sentence 4 by averaged RTs for introductory sentences 1, 2 and 3 of each text.

ERP analyses**.** We used the same six regions of interest (ROI) referenced by Pérez et al. (2015): left frontal (LF), right frontal (RF), central (C), left parietal (LP), right parietal (RP), and occipital. N400 amplitude was measured as the mean amplitude in the time window from 300 to 500ms, averaged for each ROI, and ROI was included as a predictor variable in the N400 analysis. Outliers, defined as amplitude values 2.5 standard deviations above or below the mean by language, condition, and ROI, were replaced with corresponding mean values (2.47%).

Linear mixed models (LMMs)**.** LMMs were conducted using the lmer function of the lme4 R package, version 1.1–7 (Bates, Maechler, Bolker, & Walker, 2013), with participants and items as random units, and language (L1-English vs. L2-Spanish), condition (neutral vs. non-update vs. update) and ROI (LF, RF, C, LP, RP, and O) as fixed factors. Centered values for L2 proficiency and the BSI (see Schielzeth, 2010) were also included as fixed factors. The full fixed structure thus contained two four-way interactions between language, condition, ROI and BSI, and language, condition, ROI (in the case of the N400) and L2 proficiency, as well as all their lower level interactions and main effects. Separate models were conducted for each dependent variable (sentence 4 reading times and N400). Texts containing critical words that participants did not know (11%) and texts to which the comprehension sentence was answered incorrectly (8%) were eliminated from analyses.

First, keeping the full fixed structure, we fitted each model with the maximal random effects structure using restricted Maximum Likelihood (REML): language x condition x ROI by participants and items (Barr, Levy, Scheepers, & Tily, 2013). Convergence problems were essentially solved by removing one by one the effects for which less variance was observed when the summary function was applied to the partially converged solution (for participants or items), until the model converged[17]. Secondly, keeping this previously established random effects structure (the maximal random effects structure possible), we conducted backwards stepwise model comparisons starting from the most complex model using full Maximum Likelihood estimation (ML) and removing effects that did not account for significant variance in the data, as determined by χ^2 Log-likelihood tests. Finally, for models with significant fixed effects, *p* values were provided by the anova function of the lmerTest R package, version 2.0–11 (Kuznetsova, Brockhoff, Christensen, 2012), using ML. Explained deviance was calculated using the pamer.fnc function of the LMERConvenienceFunctions R package, version 2.5 (Tremblay & Ransijn, 2013). This statistic serves as a generalization of R^2 (see e.g., Pérez et al., 2015). To follow-up on two-way interactions, we divided the data into subsets according to the factor levels of categorical variables and fitted adjusted LMMs for these subsets. To qualify three-way interactions, we compared estimates for regression slopes, t-statistics and significance values for the continuous variables within each factor level combination obtained by use of the summary function.

Results

Our results are organized into two sections. We first analyzed RTs for sentence 4, addressing the question whether readers had generated the previous inference and were able to detect a mismatch with respect to this previous information (see introduction for

[17] Removing the intercepts of participants and items or the correlation between those intercepts and the random slopes did not solve convergence problems.

predictions). Secondly, we examined N400 effects registered in response to the disambiguating word of sentence 5, assessing whether readers had revised and integrated the newly inferred concept into their situation model. Taking into account the large number of results presented in this study, we will focus on the fixed effects of each LMM. Summary details (lmerTest package) regarding model fit and random effects of each model are provided in the Appendix.

Reading times. We performed an LMM with language (L1 vs. L2), condition (neutral vs. non-update vs. update), and both individual difference indices (L2 proficiency and BSI) as fixed factors and RTs for sentence 4 as the dependent variable. The BSI and its interaction terms with the other variables, as well as the three-way interaction between language, condition and L2 proficiency were dropped from the final model during the backwards stepwise procedure as neither of them made a significant contribution to the model (*p*s >.05).

The final model (Model 1) demonstrated a main effect of condition, F (1) = 24.01, p <.001, dv = .09. As would be expected if participants had generated the facilitated inference, RTs were longer in the update (M = 1.01, SE = 0.02) compared to the non-update (M = 0.94, SE = 0.02), χ^2 (1) = 29.61, p < .001, and the neutral condition (M = 0.92, SE = 0.01), χ^2 (1) = 41.53, p < .001. The difference between the non-update and the neutral condition was significant as well, χ^2 (1) = 4.07, p = .04. In addition, there was a significant two-way interaction of language x condition, F (2) = 4.63, p = .01, dv = .02 (see Figure 1). Although the main effects of condition were significant in both languages (L1-English: F (2) = 21.01, p <.001, dv = .15, and L2-Spanish: F (2) = 5.45, p = .009, dv = .04), pairwise comparisons within language revealed different patterns. In the L1, the update condition differed significantly from both other conditions (neutral: χ^2 (1) = 30.42, p < .001, non-update: χ^2 (1) = 31.39, p <.001, and there were no differences between the latter two conditions, χ^2 (1) =

0.3, $p > .05$). In the L2, on the other hand, both update and non-update conditions differed from the neutral condition (update: χ^2 (1) = 10.61, p =.001, non-update: χ^2 (1) = 5.51, p = .02), while the difference between the update and the non-update condition was only marginal, χ^2 (1) = 3.12, p = .08. Thus, participants reacted differently to the non-update condition depending on whether it was presented in their L1 or L2, evident from significantly higher RTs in the L2 in this condition , F (2) = 2.19, p = .04, dv = .04 (no differences between languages were observed in either of the other two conditions, all Fs ≤ 1.17, ps > .05).

Reading times

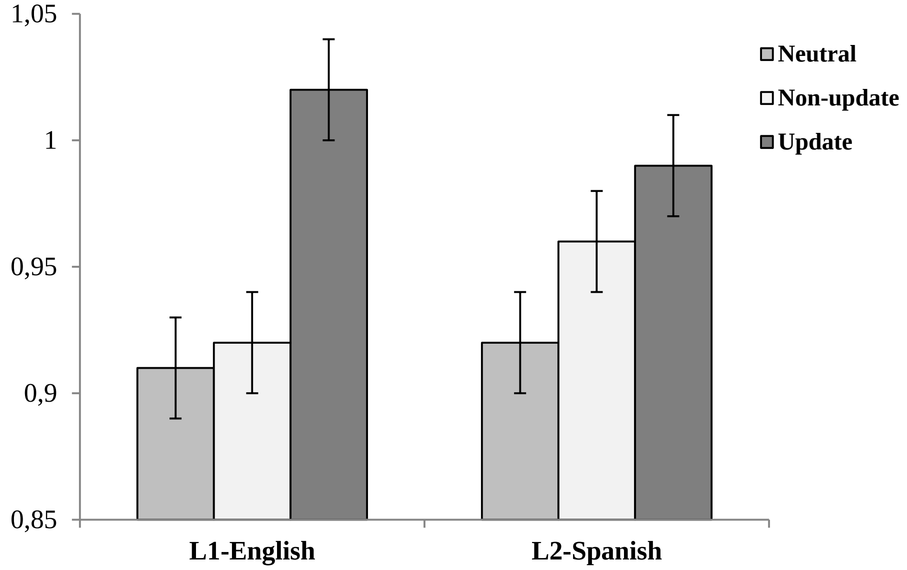

Figure 1. Reading times in L1-English and L2-Spanish for each condition.

Furthermore, participants' L2 proficiency interacted significantly with language, F (1) = 5.06, p =.03, dv = .02, as well as condition, F (2) = 7.00, p =.002, dv = .03, respectively. To follow up on the interaction between L2 proficiency and condition, there was a marginal effect of L2 proficiency in the non-update condition, F (1) = 3.88, p =.06, dv = .04, where the relationship between proficiency and RTs was negative, indicating that higher L2 proficiency was associated with shorter RTs (*b* = -0.02), paired with non-significant effects in the neutral and update conditions, *F*s ≤ 1.79, *ps* < .05. It is worth noting that the effect of L2 proficiency in the non-update condition was driven by the L2, where it was significant (L2: *b* = -0.03, *t* = -2.37, *p* = .02, L1: *b* = -0.005, *t* = -0.42, *p* > .05).

The interaction between L2 proficiency and language resulted from opposite regression slopes in the L1 (*b* = 0.02) and L2 (*b* = -0.01), although neither of these effects reached significance (*F*s = 1.73, *p*s > .05). Main effects of language, *F* (1) = 0.28, *p* > .05, and L2 proficiency, *F* (1) = 0.72, *p* > .05, were not significant.

N400. To assess whether readers were able to revise inferences, we conducted an LMM on the N400 amplitude. In this case, the variable ROI and its interactions did not make any significant contributions to the model (*ps* > .05) and were dropped in the stepwise procedure before fitting the final model, so the fixed structure contained effects for language (L1 vs. L2), condition (neutral vs. non-update vs. update) along with the individual difference indices (L2 proficiency and BSI).

In the final model (Model 2), there was a main effect of condition, *F* (1) = 8.97, *p* < .001, *dv* = .07, given that as predicted, the amplitude was less negative (reflecting a reduced N400) in the updated compared to the neutral, χ^2 (1) = 12.2, *p* < .001, and the non-updated condition, χ^2 (1) = 14.52, *p* < .001 (no amplitude differences were observed between the neutral and the non-updated condition, χ^2 (1) = 0.01, *p* > .05). As suggested by a significant two-way interaction between language and condition, *F* (2) = 18.41, *p* < .001, *dv* = 0.14, this effect was language-dependent. Specifically, the effect of condition was significant only for L1-English, *F* (1) = 17.09, *p* < .001, *dv* = .22, with a less negative amplitude in the updated condition compared to the neutral, χ^2 (1) = 13.61, *p* < .001, and non-updated condition, χ^2 (1) = 8.74, *p* = .003 (no amplitude differences were observed between the neutral and non-updated condition, χ^2 (1) = 0.65, *p* > .05), but not for L2-Spanish, *F* (1) =

1.76, $p > .05$, $dv = .02$. Differences between languages were significant in the updated condition, where the amplitude was more negative ($b = -2.04$, $t = -4.5$, $p < .001$), and in the neutral condition ($b = -2.04$, $t = -4.5$, $p < .001$), where it was less negative in L2-Spanish than in L1-English ($b = 1.00$, $t = 2.22$, $p = .03$), resulting in a less pronounced N400 effect in the L2. In addition, there was a significant interaction between language and L2 proficiency, F (1) = 6.43, $p = .01$, $dv = .05$, a marginal interaction between condition and L2 proficiency, F (1) = 2.96, $p = .05$, $dv = .02$, and two significant three-way interactions between language, condition, and L2 proficiency, $F(1) = 30.8$, $p < .001$, $dv = .07$, and language, condition, and the BSI, F (1) = 9.17, $p < .001$, $dv = .23$. No other effects reached significance, Fs (1) = 1.59, $ps > .05$.

To follow up on these interactions, L2 proficiency interacted with condition in both languages (L1: F (2) = 21.23, $p < .001$, $dv = .07$, L2: F (2) = 8.59, $p < .001$), but in different ways. In the L2, higher L2 proficiency predicted a more negative amplitude (reflecting a more pronounced N400) in the neutral condition, $b = -0.6$, $t = -2.54$, $p = .01$, whereas it predicted a less negative amplitude (reflecting a reduced N400) in the updated condition, $b = 0.94$, $t = 4.12$, $p < .001$ (the effect was also negative but non-significant in the non-updated condition, $b = -0.28$, $t = -1.19$, $p > .05$). This pattern was reversed in L1-English, where higher L2 proficiency was associated with a less negative amplitude in the neutral, $b = 0.63$, $t = 2.84$, $p = .005$, and the non-updated conditions, $b = 0.56$, $t = 2.53$, $p = .01$, whereas the regression slope was negative - yet non-significant - in the updated condition, $b = -0.16$, $t = -0.71$, $p > .05$. Thus, higher L2 proficiency was associated with a more pronounced N400 effect in the L2, but with a less pronounced N400 effect in the L1 (see Figure 2, N400).

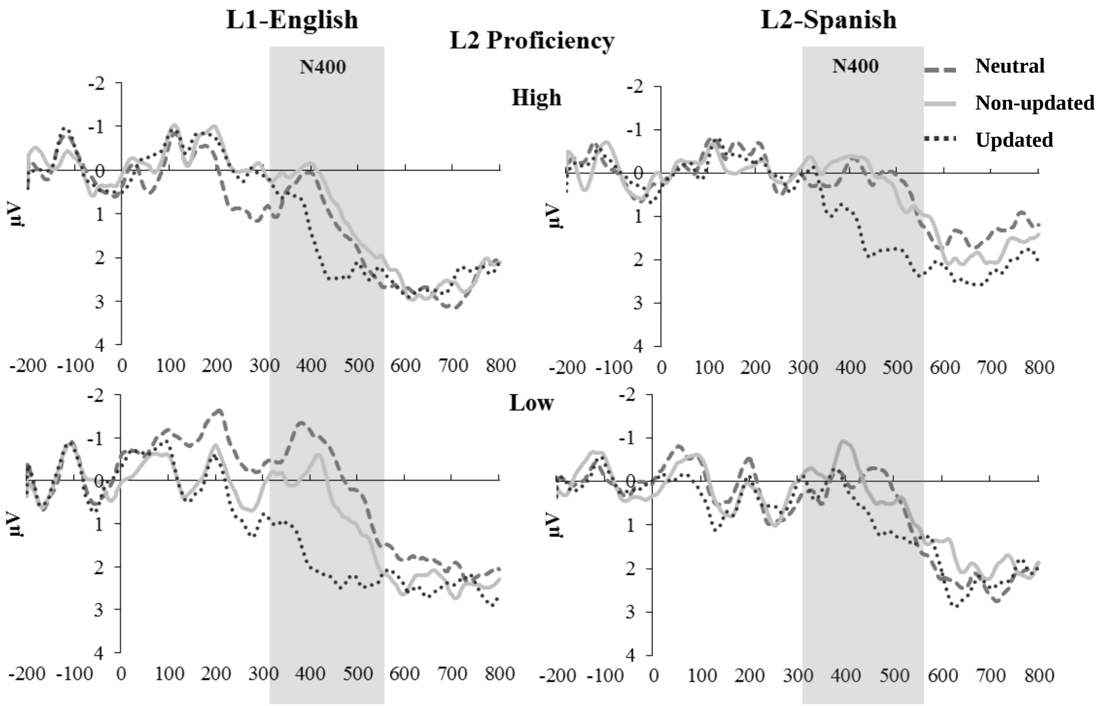

Figure 2. Graphical representation of the amplitude (in microvolts) for the N400 (dark gray column) components in the parietal lobe (mean of LP and RP), divided by language and L2 proficiency.

To clarify the role of the BSI, there were significant interactions between condition and BSI in the L1, F (2) = 13.59, $p < .001$, as well as in the L2, F (2) = 3.61, $p < .03$. In the L1, a significant effect of the BSI was observed in the updated condition, where a smaller BSI (i.e., more balanced reliance on reactive and proactive control) predicted a less negative amplitude and hence, more facilitated integration, b = -1.51, t = -2.96, p = .004, whereas effects of the BSI in the neutral, b = 0.16, and the non-updated condition, b = 0.04, were not significant, ts ≤ 0.32, ps > .05. In the L2, on the other hand, the BSI predicted the N400 amplitude in the neutral condition, where a higher BSI (marking a strong proactive tendency) was associated with a more negative amplitude, b = -1.19, t = -2.25, p = .03, whereas the relationship between BSI and amplitude was non-significant in the non-updated, b = -0.41, and updated, b = 0.25, condition, ts ≤ 0.79, ps > .05 in L1-Spanish.

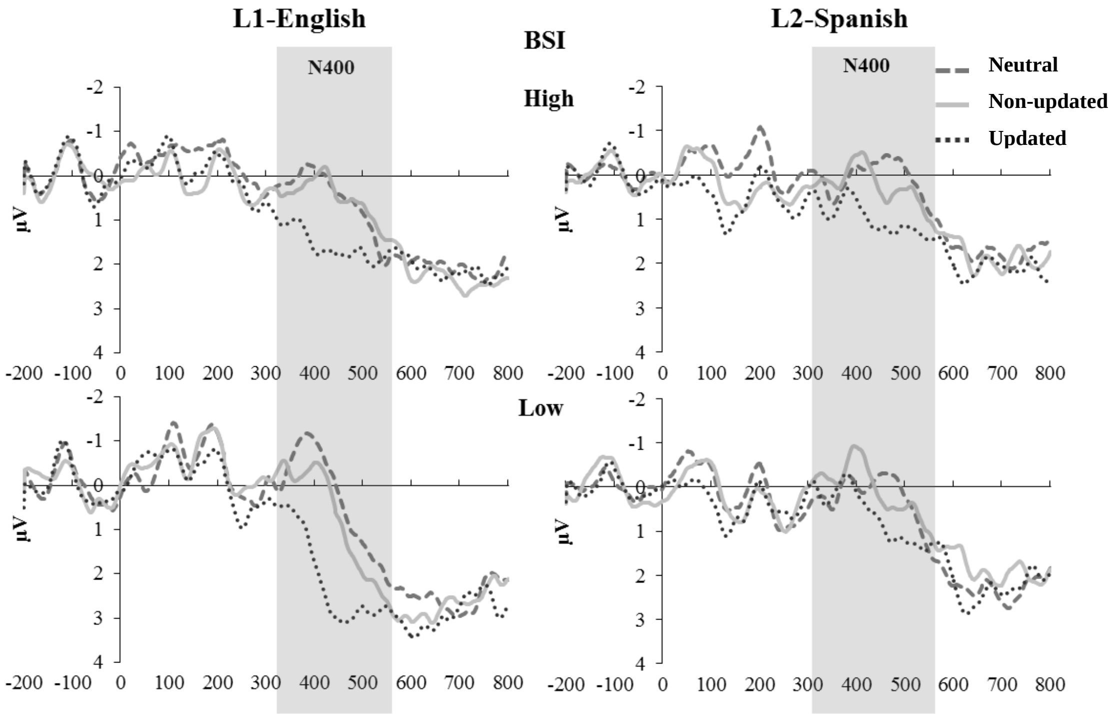

Figure 3. Graphical representation of N400 amplitude (in microvolts, dark gray column) in the parietal lobe (mean of LP and RP), divided by language and BSI.

Discussion

The aims of the present study were twofold. First, we set out to explore text-level reading in late bilinguals' L1 and L2. Previous research into native vs. non-native semantic processing (see, Clahsen & Felser, 2006, Slabakova, 2006, Martin et al., 2013) has been limited to the single word or sentence level, placing constraints on ecological validity. Semantic access and integration at the test-level depend on high-level processes such as the generation and revision of inferences, and we predicted that differences by language status might become more pronounced with increasing difficulty and complexity of the target process. Secondly, we aimed to explore to what extent differences in L1 vs L2 processing are modulated by individual variation in linguistic proficiency and cognitive control.

In line with previous studies on sentence-level semantic processing, participants' performance on the situation model revision task revealed a number of L1 vs. L2 differences. To interpret the results of our study, keep in mind that reading times for the 4th sentence of the texts allowed us to assess whether participants had generated the inference facilitated in the introduction (e.g., "fight"). In line with previous studies, L1 reading times reflected successful and efficient inference making, in that participants took longer to read information that was inconsistent (update condition: 'fight' → 'roles') compared to information that was consistent (non-update condition: 'fight' → 'aggressive') or unrelated (neutral condition: 'fight' → 'hair') to the facilitated inference. When reading in their L2, however, participants took longer to read both consistent (non-update) and inconsistent information (update) compared to unrelated (neutral) information. This pattern of results suggests that in the L2, inference generation continued throughout sentence 4 reading, and thus, was slower and less efficient than in the L1. More specifically, it seems that when reading in their L2, readers needed the additional, consistent information given in the non-update condition in sentence 4 ('*…more and more aggressive'*) in order to generate and commit to the inference biased in the introduction, whereas they were able to form this inference quickly and with less input when reading in their L1.

The next question, then, was whether participants were able to use the new information they received in the update condition of sentence 4 to revise their initial inference. To answer this question we consulted the N400 components elicited by the disambiguating word ('play') in sentence 5. When reading in their L1, participants were able to revise their initial inference when receiving information that was inconsistent with the originally facilitated interpretation, but consistent with an alternative interpretation, as reflected by reduced N400 amplitudes and thus, greater ease of integration in the updated condition ('roles' → 'play'), compared to the non-updated ('aggressive' → 'play') and the neutral condition ('hair'→ 'play'). In the L2, on the other hand, N400 effects were much less marked. Larger N400 amplitudes in the updated condition (compared to L1) suggest that readers experienced difficulties to revise inferences in their L2. Interestingly, differences by language status, in this case, in terms of smaller N400 amplitudes, were also observed in the neutral condition which does not require or facilitate inferential revision. To understand this effect, note that contrary to the neutral condition, N400 amplitudes for the L1 and L2 were similar in the non-updated condition, although the disambiguating word should be equally unexpected in both conditions. The difference between the neutral and non-updated condition lies in the temporal proximity of inconsistent information when reading sentence 5. In the non-updated condition, inconsistent information was presented very recently (‘fight’ → ‘aggressive’ → ‘play’), whereas in the neutral condition, it was implicitly presented further back (it has to be inferred from the introduction of the text), and the most recent information presented in sentence 4 was not really inconsistent with the disambiguating word (‘fight’ → ‘hair’ → ‘play’) as it was in the non-updated condition.

To sum up, the results of the situation model revision task suggest that the efficiency of inference generation and especially revision is overall reduced in late bilinguals’ L2, relative to their L1, in line with previous evidence for smaller semantic effects in L2 compared to L1 observed at the sentence level (e.g., Martin et al., 2013, Newman & Tremblay, 2012). These limitations were observed although L2 proficiency in our sample was very high overall. Nevertheless, our data align with those of others in suggesting that L1 vs. L2 differences might ultimately be due to proficiency asymmetry between the two languages. Across processes, processing differences between the L1 and L2 were attenuated with higher L2 proficiency. Thus, reading times in the non-update condition (‘fight’ → ‘aggressive’) were shorter in participants with higher L2 proficiency, reflecting more efficient and native-like inference generation (keep in mind that prolonged reading times in the non-update compared to the neutral condition were one of the key differences between L1 and L2 reading). Similarly, revision was more native-like with higher L2 proficiency, as indicated by smaller N400 amplitudes in the updated condition (‘roles’ → ‘play’). Finally, the amplitude of the N400 elicited by the neutral condition in the

L2 was increased with higher L2 proficiency, indicating more native-like processing overall.

In line with others, we propose that processing differences by language status might be due to the fact that in L2 reading, cognitive resources might be depleted to ensure lower-level processing (such as lexical processing), leaving fewer resources available for conceptual processes (see, for example, Segalowitz, Watson, & Segalowitz, 1995, Horiba, 1996, Yang, 2002, Horiba & Fukaya, 2015). Inferential revision in particular is a resource-demanding process (see Pérez et al., 2015). Furthermore, the process of overriding a previous inference likely requires inhibition, and there is evidence that the inhibition of irrelevant meaning is less efficient in L2 compared to L1 reading (Frey, 2005). Thus, processing differences between the L1 and L2 might be mediated by the availability of cognitive resources. One of the aims of our study was to explore to which extent individual differences in cognitive control would modulate these differences. Interestingly, the results of our study suggest that different control styles support text-level semantic processing in L1 and L2, respectively. In L1, individual differences in cognitive control predicted inferential revision but not inference generation, which is in line with previous findings (see Pérez et al., 2015). Specifically, revision was most efficient in participants whose performance on the AX-CPT reflected a balance between reactive and proactive control, that is, efficient engagement and disengagement of reactive mechanisms in a task set that strongly favors reliance on proactive control. To understand this result, keep in mind that proactive control is implemented through sustained maintenance of the task set (here, the situation model incrementally built up) and a processing bias towards related information. Thus, very strong reliance on proactive control can reduce flexibility to adapt to an unexpected turn of events. Furthermore, reactive control as measured by the AX-CPT has been related to inhibition (Morales et al., 2013), a process that is likely involved in overriding the initial inference in revision (see Pérez et al., 2015).

Conversely, in the L2, participants whose AX-CPT performance reflected strong reliance on proactive control were the ones who showed the largest N400 effects, although proactive control did not predict revision in the L2, but the perception of the disambiguating word in the neutral condition as inconsistent. We related smaller N400 amplitudes in the neutral condition to difficulties to maintain the situation model over time while continuing to read unrelated information in the L2. Given that proactive control is implemented through continuous maintenance of the task set (in this task, the situation model) and is resource-costly, thus reflecting high WM capacity (Braver, 2012), it seems plausible that this effect was attenuated in participants who showed a strong tendency towards proactive control.

Interestingly, these results also contribute to our understanding of the nature of L2 processing. Recent theoretical proposals hold that L2 processing tends to be less proactive than L1 processing, and that this factor accounts for many quantitative and qualitative differences observed between L1 and L2 across linguistic domains (RAGE model, Reduced Ability to Generate Expectations, Günter & Rohde, 2013; regarding syntactic processing, see Lew-Williams & Fernald 2010, Grüter, Lew-Williams & Fernald 2012, Hopp, 2013, regarding semantic processing, see Martin et al., 2013). Underlying this notion is the understanding that typical L1 comprehension is highly proactive, in that speakers continuously predict upcoming information on the basis of incrementing lexical, semantic and morphosyntactic cues. Our observations support the view that L2 processing tends to be more reactive in nature: those participants who rely heavily on proactive control process show more native-like L2 processing, whereas processing efficiency in the L1 is not constrained by the individual tendency towards proactive control. Note also that to some extent, proactive control and L2 proficiency play a similar role in L2 processing (both were associated with a larger N400 amplitude in the neutral condition), indicating that to some degree, cognitive and linguistic abilities can compensate each other. Although the revision process was exempt from this compensation, it is possible that modulatory effects would have emerged with a different operationalization of selective mechanisms of cognitive control (e.g., in terms of WM and inhibition).

Finally, some attention should be dedicated to an unexpected finding regarding the role of L2 proficiency in L1 processing. We found that L2 proficiency predicted performance not just in the L2 but also in the L1. Contrary to L2 processing, with higher proficiency in the second language, the revision of initial inferences was less efficient, reflected by larger N400 amplitudes in the update condition (‘roles’ → ‘play’), and thus, smaller N400 effects. This means that L1 vs. L2 processing differences were less marked in participants with higher L2 proficiency, but not just due to enhanced processing efficiency in the L2, but also to reduced efficiency in the L1. Although unexpected, this finding coheres with some recent evidence suggesting that acquisition of a second language later in life can modulate an already established L1 (e.g., Athanasopoulos, Dering, Wiggett, Kuipers, & Thierry, 2010, Baus, Costa, & Carreiras, 2013, Chang, 2012, Linck, Kroll, & Sunderman, 2009, Malt, Li, Pavlenko, Zhu1 & Ameel, in press). The observation of smaller N400 effects in the most balanced bilinguals also mirrors the findings of one previous study where semantic effects were generally reduced in bilinguals’ compared to monolinguals’ L1 (Ardal, Donald, Meuter, Muldrew & Luce, 1990). These data suggest that there is a balance between L1 and L2 processing efficiency in active bilinguals: to reach very high levels of proficiency in their L2, late bilinguals might “sacrifice” processing efficiency in their L1, or alternatively, it could be the case that a permeable L1 system that is susceptible to change is requisite for reaching native-like proficiency in a late L2 (see Kroll, Bobb, & Hoshino, 2014). Although further study is needed to explore the mechanisms and temporal dynamics underlying this relationship, these findings speak to an evolving and reciprocal relationship between language systems.

Conclusion

To sum up, the present study extends previous research into sentence processing by showing the efficiency of high-level semantic processes such as inference generation and revision is reduced in an L2 acquired late in life, compared to the native language. Modulatory effects suggest that these processing differences may be ultimately rooted in reduced linguistic proficiency and consequentially, limited availability of cognitive resources to engage proactive processes in the L2. Thus, very high proficiency in the L2 can, in principle, compensate non-native language status, and to some extent, individual differences in cognitive control can compensate limitations in linguistic proficiency. Modulatory effects of L2 proficiency on the native language bear witness of a bidirectional and dynamic relationship between a bilingual's language systems. Further study is needed to fully understand the dynamic interaction between L1 processing, L2 processing, linguistic proficiency and cognitive control.

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Appendix.

Model 1. Fit Indices and Random Effects of Linear Mixed Model on sentence 4 reading times.

Model 1*			
AIC	**BIC**	**logLik**	**Deviance**
-969.5	-739.6	526.8	-1053.5
Random effects			
	Variable	**Variance**	**SD**
Item	(Intercept)	0.0064	0.08
	Language	0.0009	0.03
	Condition 1	0.0006	0.03
	Condition 2	0.0007	0.03
	Language x Condition1	0.0013	0.04
	Language x Condition2	0.0004	0.02
Participant	(Intercept)	0.0026	0.05
	Language	0.0004	0.02
	Condition 1	0.0003	0.02
	Condition 2	0.0001	0.01
Residual		0.0262	0.16

* Random effects based on effect coding, with Language = L1-English and Condition = Neutral coded as baseline, Condition = Update coded as 1, and Condition = Non-update coded as 2.

Model 2. Fit indices and random effects of Linear Mixed Model on N400 amplitudes.

Model 2			
AIC	**BIC**	**logLik**	**Deviance**
68878.0	69241.3	-34389.0	68778.0
Random effects			
	Variable	**Variance**	**SD**
Item	(Intercept)	2.69	1.64
	language	1.79	1.34
	condition 1	3.05	1.75
	condition 2	3.08	1.75
Participant	(Intercept)	1.40	1.18
	Roi1	0.17	0.41
	Roi2	0.52	0.72
	Roi3	0.55	0.74
	Roi4	0.18	0.42
	Roi5	0.49	0.70
Residual		36.21	6.02

* Random effects based on effect coding, with Language = L1-English, Condition = Neutral, and Roi = C coded as baseline, Condition = Update coded as 1, and Condition = Non-update coded as 2, Roi = RP coded as 1, Roi = RF coded as 2, Roi = O coded as 3, Roi = LP coded as 4, and Roi = LF coded as 5.

Chapter III

General discussion

This work set out to examine the connection between language and executive control in bilinguals. Recent theoretical accounts assume that control demands are enhanced in bilingual compared to monolingual language processing, and that these additional demands are met in the form of domain-general resources (see, for example, Bialystok, 2001, Kroll & Bialystok, 2013, Stocco, Yamasaki, Natalenko, & Prat, 2014). Evidence for this compound hypothesis comes from data showing i) enhanced executive control in bilinguals compared to monolinguals (e.g., Adesope, Lavin, Thompson & Ungerleider, 2010, Bialystok, 2001, Bialystok, 2009), suggesting that linguistic experience can modulate the executive control system, ii) impaired linguistic performance in bilinguals compared to monolinguals (e.g., Portocarrero, Burright & Donovick, 2007, Yan & Nicoladis, 2007), interpreted as a marker of increased cognitive demands associated with linguistic processing due to bilingualism, and iii) correlation of executive control and language control functions (e.g., Lev-Ari & Keysar, 2014, Marian, Chabal, Bartolotti, Bradley, & Hernandez, 2014, Pivneva, Mercier, & Titone, 2014), suggesting that linguistic processes (particularly in bilinguals) in fact rely on domain-general executive control. However, a heated debate has evolved over the last years regarding the reliability of data supporting this view as well as the validity of the conclusions drawn from them (Antón et al., 2014, De Bruin, Treccani, & Della Sala, 2015, Duñabeitia et al., 2015, Paap & Greenberg, 2013).

The experimental series reported in this dissertation addresses the presented hypothesis and its implications from different perspectives, and makes several contributions that are both conceptual and methodological in nature. Experiments 1 and 2 focused on the interaction of cognitive costs and benefits of bilingualism in school-aged children. More often than not, experimental tasks used to assess cognitive development and ability rely on both linguistic and domain-general processes, especially with increasing complexity and practical relevance (see Blom, Küntay, Messer, Verhagen, & Leseman, 2014, Kempert, Saalbach, & Hardy, 2011). Furthermore, bilingual costs and benefits have been attributed to the same source (e.g., Bialystok, 2009, Kroll & Bialystok, 2013). However, only a handful of studies have considered their additive contribution the same task or target construct. Thus, the first experimental series aimed to understand how multiple underlying processing differences in separate domains may influence complex task performance. The results of Experiment 1 suggest that emergent bilingualism has multiple modulatory effects on the development of verbal Working Memory. More specifically, second language immersion seemed to boost the development of executive updating, while simultaneously delaying development in linguistic processing efficiency. Both are crucial to the development of verbal WM, producing a pattern of counteracting effects. Experiment 2 focused on reading comprehension as a complex literacy skill and again, we found that underlying components - linguistic processing, on the one hand, and memory and reasoning capacity, on the other hand, as identified by Principal Component Analysis - were differentially affected by emerging bilingualism, with bilinguals showing enhanced memory and reasoning capacities, and monolinguals showing more efficient linguistic processing. The two components made independent contributions to reading comprehension, leading to overall equivalent performance at the level of complex skill in both groups. Both experiments consistently revealed a disadvantage in linguistic processing (note that children were tested in their native and dominant language) and an advantage in the memory domain for bilingual compared to monolingual participants. Note also that Experiment 2 validates the premise of Experiment 1 that reading span depends to similar degrees of domain-specific linguistic and domain-general processes.

The aim of Experiments 3 and 4 was to ascertain to what extent individual factors determine the degree and type of cognitive adaptation effects in bilingual participants. Dichotomous conceptualizations of language status whereby individuals are classified as either monolingual or bilingual are problematic in light of the diversity across bilingual environments (see Luk & Bialystok, 2013) and our goal was to shed some light on the role of more specific and variable aspects of bilingualism. We focused on characteristics of bilingual language use, namely the degree of active immersion in the L2 and language switching habits in late, non-balanced bilinguals. The results of both experiments suggest that active use of the less dominant language is associated with enhanced executive control, particularly in regards to interference resolution, as evidenced by smaller interference costs in more immersed bilinguals compared to less immersed bilinguals or monolinguals. Enhanced flexibility as reflected by reduced switch costs (Experiment 3) and mix costs (Experiment 4) was predicted by language switching behavior. The results of the two experiments are complementary, as Experiment 3 relied on a longitudinal design, whereas experiment 4 was based on a cross-sectional comparison.

Finally, in Experiment 5 we examined the relationship between individual differences in executive control and linguistic processing in the L1 and L2, which in turn allows us to contrast the executive control demands of native and nonnative language processing. The need to use a nonnative and less proficient language is one of the factors that may increase the cognitive demands of language processing in bilinguals compared to monolinguals (see also Experiments 3 and 4). Generally speaking, the results of Experiment 5 suggest that high-level linguistic processes such as inference generation and revision are less efficient in the L2 compared to the L1, despite the high level of L2 proficiency in our sample. Differences in processing efficiency were modulated by individual differences in both linguistic proficiency and executive control, in that both high proficiency in the L2 and a strong tendency towards proactive control were associated with more native-like L2 processing. Crucially, both native and non-native language processing were predicted by individual differences in executive control, but they were clearly associated with differential control demands to the point that mutually exclusive control styles were associated with optimal performance in both languages. In the L2, proactive control was associated with more efficient and native-like processing, while L1 processing was most efficient in participants who showed the ability to balance reactive and proactive control modes very well. Thus, different cognitive profiles benefitted processing efficiency in the L2 vs. the L1. Moreover, within each language, different processes were predicted by individual differences in cognitive control. In the L2, it was sustained maintenance of the situation model that was aided by stronger proactive control, whereas in the L1, inferential revision was selectively predicted by balanced reliance on proactive/reactive control.

Combined, the empirical results of this experimental series contribute to our understanding of the relationship between language and domain-general cognitive control. They are principally in line with the assumption that linguistic experience shapes cognitive systems outside the language domain. However, this relationship is not unidimensional, and more complex than previously suggested. Thus, it is not just a matter of more demanding language experiences leading to superior executive control, but a more specific adaptation to the demands of individual experiences and context (see Experiments 3 and 4). Conversely, our data support the notion that language processing taps mechanisms of domain-general cognitive control, and again, they suggest that different language functions rely on control mechanisms not just in variable degree but of variable nature (see Experiment 5). What constitutes an adaptive configuration of the executive system depends on the linguistic setting and the specific language operations it requires and this affects the points of convergence of language control and domain-general control that emerge in experimental settings. Insofar, the outcomes of our work are in line with the predictions of the adaptive control hypothesis (Green & Abutalebi, 2013) and recent research inspired by it (e.g., Hartanto & Yang, 2016).

Several dimensions can be extracted from the data. First, it is important to distinguish between control mechanisms that stabilize the current task set vs. those that enhance flexibility to attend to multiple task sets and unexpected behavioral demands (for more details regarding their functional, structural and genetic separation, see Bilder, 2012).

This distinction is relevant not only for multiple language use in bilinguals, but also in regards to differential processes within-language. To illustrate, consider the cognitive demands of switching back and forth between languages vs. remaining within language in bilinguals (Experiments 3 and 4), or in the case of unilingual processing, the demands of maintaining a situation model while reading both related and unrelated information vs. committing to a new situation model when inconsistent information is encountered (Experiment 5).

Secondly, language control functions can be effortful or relatively automatized. Again, this is true for processes that involve multiple languages, such as switching (see Experiments 3 and 4) as well as unilingual processes (see Experiment 5). Our results suggest that adaptive effects emerge when processing is effortful. For example the combined outcome of Experiments 3 and 4 suggests that language switching experience benefits cognitive flexibility if it is controlled and effortful. In addition, Experiment 5 suggests that some processes that are automatic in the L1 might require cognitive control in the L2, and in this sense, support the assumption that reduced automaticity in a non-native language is one aspect that increases the executive demands of language processing in bilinguals (see also Duñabeitia & Carreiras, 2015). It should be noted, however, that early balanced bilingualism, where the line between L1 and L2 is blurred, may very well be associated with its own set of characteristic processing demands and cognitive adaptation effects (see Tao et al., 2011). Our data are not really informative in this regard, although we did observe that certain linguistic processes seemed to depend on cognitive control in the L1 but not the L2 (see Experiment 5), possibly because the level of difficulty of the process in question was not compensable in the L2.

Finally, our experimental series provides further evidence to suggest that the use and acquisition of a second language have consequences for a previously entrenched L1. We observed this effect in the form of slower or generally less efficient L1 processing in children immersed in an L2 at school compared to monolinguals (Experiments 1 and 2), as well as less proficient L1 processing with increased L2 proficiency (Experiment 5). These findings mirror earlier results, and whether they be due to effects of distributed linguistic exposure, cognitive load, or both, they support the notion that both native and non-native language systems are susceptible to change and affect each other bidirectionally. On a related note, our data suggest that specific linguistic deficits can be compensated by means of domain-general cognitive resources. This is one of the main findings of Experiments 1 and 2, but the relationship of general compensability can also be observed for the L1 and L2 in Experiment 5. This sums up the conceptual conclusions that can be drawn from this work in regards to linguistic experience, language processing, executive control, and the interaction between them.

In addition, the experimental series makes various contributions of methodological nature. Specifically, it highlights possibilities to circumvent some of the problems that are inherent to this field of study. The first issue concerns the reliability of effects and the sensitivity of our research methods. Processing differences that attest to the relationship between multiple language use and executive control are subtle, and problems of task impurity hinder their detectability, especially given that multiple counteracting effects might cancel each other out. The use of Principal Component Analysis in Experiment 2 illustrates this problem - note that all tasks load on both components at least in some degree. Analyzing principal components maximized the detectability of systematic processing differences (see also Engel de Abreu, Cruz-Santos, Tourinho, Martin & Bialystok, 2012). With smaller sample sizes and task batteries, identifying separate sources of variance in the data might be possible through careful task selection (see Experiment 1) or by extracting multiple measures from task performance (see our Experiment 5, see also Bialystok, Craik, & Luk, 2008b, Luo, Luk, & Bialystok, 2010).

Second is the issue of internal validity, the question of whether processing differences are really due to multiple language use or to confounding factors as many have claimed (e.g., Morton & Harper, 2007, Paap & Greenberg, 2013). Establishing experimental control in the case of bilingualism is tricky because it is hardly possible to randomly assign participants to one group or the other. The combination of longitudinal and cross-sectional research proved useful, as both allowed us to control for different classes of confounding effects.

Finally, there is the issue of ecological validity. In addition to being subtle, processing differences in the context of bilingualism and cognitive control have mostly been observed for relatively basic cognitive processes. This raises the question to what extent research findings are practically relevant. Ecological validity is increased by extending research to the level of complex skill (Experiments 2 and 5). In addition, research into the cognitive consequences of bilingualism in an educational context is of particular relevance, because here, contrary to many other settings, individuals and policy makers actively choose bilingualism.

Concluding remarks

Data accumulated over the last two decades point to a link between bilingualism and cognitive control. The debate surrounding this topic has often been reduced to the dichotomy of monolingualism vs. bilingualism and the question whether one benefits cognitive development and attainment more than the other. In line with other recent studies and theoretical proposals (see, e.g., Kroll & Bialystok, 2013, Luk & Bialystok, 2013) our data suggest that the dichotomous distinction between monolinguals and bilinguals is of limited use to characterize the intricacies of the underlying relationship. In addition, we believe the main goal of research in this context should not be to weigh costs and benefits of bilingualism against each other. More often than not, the cognitive consequences of bilingualism (whether beneficial or detrimental) are mere byproducts of more important life decisions and fundamental circumstances. The identification of cognitive costs and benefits as such is relevant to an extent that they have practical consequences and lead to inequalities that may or may not be compensable. It is mostly within the educational context that research findings can inform individual and policy decisions. Our results in this regard are hopeful, suggesting that processing deficiencies in different areas can be compensated at the complex skill level, leaving neither bilingual nor monolingual children behind, at least within the normally developing population.

What is more interesting is what these findings can tell us about cognitive control, language processing, and their interaction. The present work depicts the relationship between linguistic experience, cognitive control and linguistic processing as a complex and versatile one. Bilingualism - the acquisition, knowledge, and use of multiple languages - is one aspect among others that factors into this relationship and in many ways serves as an optimal example to study its nature and boundary conditions. Much more research is needed to understand how the different elements that enter into the equation affect and condition each other. For example, while many studies have examined the effect bilingualism has on executive control, much less is known about the converse relationship. Individual variation in executive control might determine who becomes a fully functional bilingual in the first place (see the results of Hernandez, Greene, Vaughn, Francis, & Grigorenko, 2015). In a recent study by Kapa and Colombo (2014), individual differences in working memory and inhibitory control predicted how well participants learned an artificial language within a given time frame. Future research should consider the possibility of a bidirectional relationship more thoroughly. Another neglected factor lies in the temporal dynamics of relevant effects. Inter-individual differences in language status are not static. Individuals go through periods of functional monolingualism and bilingualism because life circumstances change. Studies that have started to consider this dimension tend to assume a unidirectional development towards increasing bilingualism, but it is unclear what happens after the initial stages of L2 acquisition and bilingualism, and if participants revert to monolingual L1 use (for a notable exception, see Bogulski et al., 2015). Finally, given the diversity of linguistic experiences and adaptive cognitive effects, it seems as though it would be useful to give up the perspective of monolingual normativity, where bilingualism is treated as a special circumstance and its consequences and specificities are treated as divergence from the norm. More than half of the world's population is bilingual, and the majority is probably best characterized as somewhere between absolute monolingualism and balanced bilingualism. In that sense, the assumption of a monolingual norm seems of limited usefulness. In sum, there are many potential avenues for future research to address this topic more holistically.

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Capítulo IV

Resumen y discusión general

Este trabajo tiene como objetivo examinar la conexión entre el lenguaje y el control cognitivo. Muchos autores en el campo del bilingüismo y la cognición sugieren que el procesamiento lingüístico supone una mayor demanda cognitiva en las personas bilingües que en las personas monolingües, y que para atender a dicha demanda se emplean procesos ejecutivos de dominio general (por ejemplo, Bialystok, 2001, Kroll & Bialystok, 2013, Stocco, Yamasaki, Natalenko, & Prat, 2014). Esta perspectiva teórica está apoyada por los datos que reflejan i) un mayor control ejecutivo en bilingües con respecto a monolingües (p. ej., Adesope, Lavin, Thompson & Ungerleider, 2010, Bialystok, 2001, Bialystok, 2009), lo que sugiere que la experiencia lingüística puede modular el sistema ejecutivo ii) un peor rendimiento lingüístico en bilingües respecto a monolingües (p. ej., Portocarrero, Burright & Donovick, 2007, Yan & Nicoladis, 2007), lo que se ha interpretado como consecuencia de una mayor demanda cognitiva asociada al procesamiento lingüístico en el caso de los bilingües, iii) una correlación entre las funciones ejecutivas y lingüísticas (p. ej., Lev-Ari & Keysar, 2014, Marian, Chabal, Bartolotti, Bradley, & Hernandez, 2014, Pivneva, Mercier, & Titone, 2014), que sustenta la idea de que, efectivamente, los procesos lingüísticos (especialmente en el caso de los bilingües) se apoyan en los recursos ejecutivos de dominio general. Sin embargo, en los últimos años se ha producido un debate cada vez más intenso en torno a la fiabilidad de los datos que apoyan esta perspectiva y a la validez de las conclusiones extraídas (Antón et al., 2014, De Bruin, Treccani, & Della Sala, 2015, Duñabeitia et al., 2015, Paap & Greenberg, 2013).

Teniendo en cuenta la evidencia mixta con respecto a las diferencias cognitivas entre monolingües y bilingües, muchos estudios empíricos y algunas perspectivas teóricas recientes sugieren que la relación entre el control cognitivo y el bilingüismo es mucho más compleja que previamente se había asumido (véase Green & Abutalebi, 2013). Según la hipótesis del control adaptivo (Green & Abutalebi, 2013), las consecuencias cognitivas del bilingüismo son selectivas y específicamente basadas en las características del uso de múltiples idiomas, y su detección depende de la sensibilidad de los métodos disponibles para detectarlas (véase Bialystok, 2009, Kroll & Bialystok, 2013).

La serie experimental descrita en esta tesis aborda las cuestiones principales e implicaciones derivadas de la perspectiva teórica del control adaptativo desde diferentes puntos de vista, y sus aportaciones son de naturaleza tanto conceptual como metodológica. Los Experimentos 1 y 2 están enfocados a investigar la interacción entre los costes y los beneficios del bilingüismo en niños en edad escolar. Muchas veces, las tareas experimentales empleadas para evaluar el desarrollo y las habilidades cognitivas reflejan tanto procesos lingüísticos como procesos cognitivos de dominio general, sobre todo cuando se trata de tareas de mayor complejidad y relevancia aplicada (veáse Blom, Küntay, Messer, Verhagen, & Leseman, 2014, Kempert, Saalbach, & Hardy, 2011). Además, tanto las consecuencias beneficiosas como las adversas se han atribuido a un mismo origen (p. ej., Bialystok, 2009, Kroll & Bialystok, 2013). No obstante, son escasos los estudios experimentales que han considerado la contribución aditiva de costes y beneficios a la misma tarea o al mismo constructo. Por lo tanto, la primera serie experimental tenía como objetivo explorar cómo las diferencias en varios procesos básicos dentro de diferentes dominios cognitivos pueden afectar al desempeño global en una tarea compleja. Los resultados del Experimento 1 señalan múltiples efectos moduladores del bilingüismo emergente en el desarrollo de la memoria de trabajo verbal. Por un lado, la inmersión en un segundo idioma parece estimular el desarrollo de la monitorización ejecutiva, mientras que se observa un retraso en el desarrollo del procesamiento lingüístico. Ambos procesos son fundamentales en el desarrollo de la memoria de trabajo verbal, por lo cual se produce un patrón de efectos contrarios. El segundo experimento estaba focalizado en la comprensión lectora y, de nuevo, se observaron efectos disociables en los procesos subyacentes. Los resultados de un Análisis de Componente Principales sirvieron para identificar por un lado, un componente de procesamiento lingüístico, y por otro lado, otro componente de memoria y razonamiento. Concretamente, los niños con bilingüismo emergente demostraron mayores capacidades de memoria y representación, mientras que los monolingües mostraron mayor eficiencia en el procesamiento lingüístico. Los dos componentes explican parte de la varianza en comprensión lectora, de manera que el rendimiento a nivel global es equivalente en ambos grupos. Tanto el primer experimento como el segundo revelaron una desventaja en el procesamiento lingüístico (es importante destacar que los niños fueron evaluados en su lengua materna y dominante) y una ventaja en el dominio de memoria en los bilingües respecto a los monolingües. También cabe mencionar que el segundo experimento da validez a las conclusiones del primer experimento al mostrar que la tarea de amplitud lectora depende en igual medida de procesos de dominio específico lingüístico y de procesos cognitivos de dominio general.

Los Experimentos 3 y 4 tenían como objetivo comprobar hasta qué punto los efectos de adaptación cognitiva asociada al bilingüismo están determinados por factores individuales. La conceptualización dicotómica del estatus lingüístico basada en la distinción entre personas bilingües y monolingües es problemática dada la inmensa variabilidad entre diferentes contextos y ámbitos bilingües (véase Luk & Bialystok, 2013) y nuestro objetivo fue esclarecer el papel de varios aspectos específicos y variables en el contexto del bilingüismo. Nos centramos en características de uso de múltiples idiomas, más concretamente, en el grado de inmersión activa en el L2 y los hábitos de cambio de idioma en un grupo de bilingües no balanceados y de edad de adquisición tardía. Los resultados de ambos experimentos señalan que el uso activo del idioma más débil está asociado a un mayor control ejecutivo, particularmente en el caso de las habilidades de resolución de interferencia, reflejado en un menor coste de interferencia en los bilingües más inmersos respecto a los menos inmersos y los monolingües. En cambio, los hábitos de cambio entre idiomas predecían el nivel de flexibilidad cognitiva, reflejada el de cambio (Experimento 3) y el coste mixto (Experimento 4). Los resultados de los dos experimentos son complementarios, ya que el Experimento 3 se basaba en un diseño longitudinal, y el Experimento 4, en un diseño trasversal.

Por último, en el quinto experimento investigamos la relación entre las diferencias individuales en control ejecutivo y procesamiento lingüístico tanto en L1 como L2, lo que nos permitía contrastar la carga ejecutiva del procesamiento lingüístico en ambos idiomas. La necesidad de comunicar en un idioma no nativo en el que se tiene una menor competencia es uno de los factores que aumentan la demanda cognitiva del procesamiento lingüístico en las personas bilingües (véanse también los Experimentos 3 y 4). A nivel general, los resultados del quinto experimento indican que los procesos lingüísticos de alto nivel como la generación y la revisión de inferencias son menos eficientes en el segundo idioma que en el primero, pese al alto nivel de competencia en L2 de la muestra. Las diferencias en la eficiencia de procesamiento se veían moduladas por las diferencias individuales en competencia lingüística y control ejecutivo, de manera que tanto un alto nivel de competencia en el L2 como una fuerte tendencia hacia un modo de control proactivo, se asociaron a un procesamiento del L2 más parecido al procesamiento nativo. Es importante destacar que las diferencias individuales en el control ejecutivo predecían tanto el procesamiento nativo como el procesamiento no nativo. Sin embargo, los procesos de control demandados en ambos idiomas son diferentes, tanto que los modos de control asociados a mayor eficiencia dentro de cada idioma son directamente opuestos. En el L2, el control proactivo estaba asociado a un procesamiento más eficiente y similar al procesamiento nativo, mientras que en el L1, el mejor rendimiento se observó en los participantes que muestran la habilidad de balancear control reactivo y proactivo. Por lo tanto, la eficiencia lingüística en L1 y L2 se vio beneficiada por diferentes perfiles cognitivos según el idioma. Además, las diferencias individuales en el control cognitivo predecían procesos distintos dentro de cada idioma. Así, en el L2, el control cognitivo (concretamente, la tendencia hacia el control proactivo) servía de apoyo a los procesos de mantenimiento del modelo de situación mientras que en el L1, el efecto modulador del control cognitivo (en este caso, el balance entre control proactivo y reactivo) se observó en el proceso de revisión inferencial.

En síntesis, los resultados empíricos de la serie experimental contribuyen hacia una mejor comprensión de la relación entre el lenguaje y el control cognitivo de dominio general. En un principio, concuerdan con la idea de que la experiencia lingüística deja huella en los sistemas cognitivos fuera del dominio lingüístico. No obstante, esa relación no es unidimensional, y es más compleja de lo supuesto anteriormente. De esta manera, no se trata solamente de que las experiencias lingüísticas más demandantes conlleven un control cognitivo superior, sino de una adaptación más específica a las condiciones que suponen las experiencias y contextos individuales (véanse los Experimentos 3 y 4). A su vez, nuestros datos apoyan la idea de que el procesamiento lingüístico implica mecanismos cognitivos de dominio general y, de nuevo, ponen en evidencia que distintas funciones lingüísticas se apoyan en mecanismos de control cuya naturaleza y grado son variables (véase Experimento 5). Lo que constituye una configuración adaptiva del sistema ejecutivo depende del ambiente lingüístico y de las operaciones lingüísticas específicas que requiere, y esto afecta a los puntos de convergencia del control ejecutivo y lingüístico que resaltan en el contexto experimental. En este sentido, los resultados de este trabajo concuerdan con las predicciones de la hipótesis de control adaptivo (Green & Abutalebi, 2013) y las investigaciones recientes inspiradas por ella (e.g., Hartanto & Yang, 2016).

A partir de este trabajo podemos extrapolar varias dimensiones. En primer lugar, es importante distinguir entre los mecanismos de control que dan estabilidad a la ejecución de una tarea determinada y los que capacitan la flexibilidad de atender a múltiples tareas y exigencias conductuales imprevistas (vea Bilder, 2012, para más detalles relativos a la base funcional, estructural y genética de esa disociación).La relevancia de esta distinción se da no sólo en el caso la coordinación de múltiples idiomas en las personas bilingües, sino también en relación a diferentes procesos dentro de un mismo idioma. Para ilustrar este aspecto, cabe considerar las exigencias cognitivas de cambiar entre un idioma frente a las de permanecer en el mismo idioma objetivo (Experimentos 3 y 4), o en el caso del procesamiento monoilingüe, las exigencias de mantener el modelo situacional durante la lectura de información relevante e irrelevante frente a las de asimilar un nuevo modelo cuando aparece información inconsistente con la anterior (Experimento 5).

En segundo lugar, las funciones lingüísticas pueden requerir un esfuerzo controlado o pueden ser automatizadas. De nuevo, esto se aplica tanto a los procesos que implican múltiples idiomas, como el cambio entre idiomas (véanse los Experimentos 3 y 4), como a los procesos monolingües (véase Experimento 5). En tanto a este aspecto, nuestros resultados indican que los efectos de adaptación cognitiva se dan cuando el procesamiento requiere un alto nivel de control. Por ejemplo, el resultado combinado de los experimentos 3 y 4 señala que cambiar entre idiomas beneficia la flexibilidad cognitiva sólo cuando este proceso es controlado y requiere esfuerzo. Asimismo, los resultados del experimento 5 indican que hay procesos que se realizan de manera automática en el L1 y sin embargo, requieren control cognitivo en el L2, a pesar del alto nivel de competencia en este idioma. Este hallazgo apoya la idea de que la automaticidad reducida en un idioma no nativo es uno de los aspectos que aumentan la carga ejecutiva del procesamiento lingüístico en las personas bilingües (véase también Duñabeitia & Carreiras, 2015). No obstante, es importante mencionar que el bilingüismo temprano y balanceado donde la línea entre L1 y L2 se vuelve más difusa, podría estar asociado a un conjunto propio de exigencias ejecutivas y de efectos de adaptación cognitiva (véase Tao et al., 2011). Nuestros datos no son informativos en relación a este aspecto, aunque cabe destacar que había también procesos lingüísticos que parecían depender del control cognitivo en el L1 pero no en el L2 (véase Experimento 5), posiblemente debido a un nivel de dificultad no compensable en el L2.

Por último, nuestra serie experimental aporta nuevas evidencias de que el uso y la adquisición de un segundo idioma tienen consecuencias para un L1 previamente consolidado. Este efecto se aprecia en un procesamiento lingüístico más lento o generalmente menos eficiente en niños bilingües inmersos en un L2 en el entorno escolar, respecto a niños monolingües (Experimentos 1 y 2), así como en la reducción de eficiencia lingüística en el L1 a mayor competencia de L2 (Experimento 5) Independientemente de si esta diferencia se debe a la exposición lingüística distribuida o a diferencias en la carga cognitiva, estos hallazgos concuerdan con resultados previos y apoyan la hipótesis de que los sistemas del lenguaje tanto nativo como no nativo son susceptibles al cambio y pueden afectarse mutuamente. En relación a esto, nuestros datos señalan que los recursos cognitivos de dominio general pueden compensar ciertos déficits lingüísticos. Este es uno de los resultados principales de los Experimentos 1 y 2, pero la misma relación de compensación también se puede observar en ambos idiomas en el Experimento 5. Con esto se resumen las aportaciones conceptuales que se pueden extraer de este trabajo en tanto al procesamiento lingüístico, control cognitivo, y la interacción entre los dos.

Además, la serie experimental hace varias contribuciones de naturaleza metodológica. Concretamente, señala posibles maneras de evitar algunos de los problemas fundamentales de los estudios en este contexto. En primer lugar están los problemas de la fiabilidad de los efectos y de la sensibilidad de nuestros métodos de investigación para detectarlos. Las diferencias en el procesamiento que ponen en evidencia la relación entre el uso de múltiples idiomas y el control ejecutivo son sutiles, y el problema de operacionalización e impureza de tareas puede impedir su detectabilidad, especialmente dado que distintos efectos contrarios se podrían estar contrarrestando. Este problema está ilustrado por el uso del Análisis de Componentes Principales en el Experimento 2 - cabe destacar que todas las tareas tienen peso en ambos componentes, al menos en cierta medida. Analizar los componentes principales nos permitió maximizar la sensibilidad para detectar diferencias de procesamiento sistemáticas (véase también Engel de Abreu, Cruz-Santos, Tourinho, Martin & Bialystok, 2012). En caso de que el tamaño de la muestra sea menor, una cuidadosa selección de tareas (véase Experimento 1) o la extracción de múltiples medidas de la misma tarea (véanse el Experimento 5, y también Bialystok, Craik, & Luk, 2008b, Luo, Luk, & Bialystok, 2010) pueden ayudar a identificar distintas fuentes de variabilidad en los datos.

En segundo lugar, está el problema de la validez interna: la cuestión de si las diferencias en el procesamiento se deben verdaderamente al uso de múltiples idiomas o a variables extrañas como han afirmado algunos autores (p. ej., Morton & Harper, 2007, Paap & Greenberg, 2013). Ejercer control experimental en el caso del bilingüismo es difícil, ya que las posibilidades de asignar al azar participantes a un grupo u otro son muy limitadas. La combinación de métodos longitudinales y trasversales resultó particularmente útil en este contexto, visto que ambos permiten controlar diferentes tipos de variables extrañas.

Por último, está el problema de la validez ecológica. Además de ser sutiles, los efectos en el contexto del bilingüismo y del control cognitivo se suelen observar en procesos relativamente básicos. Esto plantea la cuestión de cuál es la relevancia práctica de estos efectos. La validez ecológica es mayor cuando la investigación se extiende al nivel de habilidades complejas (véanse los Experimentos 2 y 5) ya que estas habilidades son fundamentales en la vida diaria de las personas. Asimismo, la investigación de las consecuencias cognitivas del bilingüismo en el contexto escolar es de especial relevancia teniendo en cuenta que, al contrario que en muchos otros contextos, los individuos y responsables políticos eligen activamente el bilingüismo.

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