CHAPTER 15

Cognitive mechanisms underlying performance differences between monolinguals and bilinguals

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Lifelong experience with multiple languages is believed to produce a number of executive function advantages including enhanced top-down control, improved attention, and greater working memory capacity. This bilingual advantage is generally believed to be the result of having multiple lexical representations in each language that compete for selection. More specifically, the control that is required to select the relevant from the irrelevant language in any given context is believed to require cognitive control, and practicing this control leads to enhanced executive functioning. However, the specific underlying mechanisms of language control, including inhibition, monitoring, attention, and disengagement, that lead to enhanced executive functioning are still largely unknown. This is partly due to the complex nature of both language and domain general executive functions, which are multi-faceted. Here, we highlight some possibilities for disentangling the underlying mechanisms of executive function contributing to performance differences between monolinguals and bilinguals, and suggest that disengagement of attention from previous information is an important mechanism to consider.

1. Introduction

There is an abundance of evidence that both languages for bilinguals are jointly activated in any given context, even if only one language is relevant to the task at hand (Martin et al., 2009; Spivey & Marian, 1999; Timmer et al., 2014; Thierry & Wu, 2007; Wu & Thierry, 2010, 2012; for review see Kroll et al., 2012). It has been suggested that domain-general executive functions (EFs) are recruited in order to select the appropriate language while ignoring the irrelevant language (Bialystok,

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Craik, & Luk, 2012).[1] This idea is supported by a number of studies that have shown that bilinguals perform better than comparable monolinguals on a range of EF tasks including conflict resolution (Bialystok, Craik, Klein, & Viswanathan, 2004; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009), attention (Kovács & Mehler, 2009; Kuipers, & Thierry, 2013; Soveri, Laine, Hamalainen, & Hugdahl, 2011), working memory (Morales, Calvo, & Bialystok, 2013; Soliman, 2014), and task-switching (Gold et al., 2013; Prior & MacWhinney, 2010). However, the hypothesis that frequently using control to speak/comprehend in the appropriate language leads to enhanced non-verbal executive functioning (for a review see Bialystok, Craik, Green, & Gollan, 2009) makes three assumptions: (1) that we understand the exact nature of language control, (2) that we understand the exact nature of executive function, and (3) that language control requires domain general EFs. Executive functions encompass multiple component processes including episodic retrieval of memory representations, conflict adaptation, disengagement of attention, engagement of attention, and priming, to name a few. However, many of the general conflict tasks used in the literature make it difficult to rule out a number of alternative or additive mechanisms that may be contributing to the bilingual advantage. It is our goal in this chapter to discuss some possibilities for disentangling the underlying mechanisms of EF that might contribute to performance differences between monolinguals and bilinguals on cognitive control tasks. Specifically, we highlight the importance of using tasks that can distinguish between different types of processes and then suggest that disengagement of attention might be an important mechanism to explore in future studies.

We first discuss different levels of language control and focus on the potential inhibitory processes necessary to switch between and produce output in particular target languages. This is followed by a discussion of the multifaceted nature of executive functions and how proactive and reactive forms of control can be distinguished. Next, executive functions are discussed in relation to non-inhibitory frameworks, including memory and attentional processes. Finally, we suggest that disengagement of attention might be contributing significantly to bilingual performance advantages over monolinguals.

2. Language control

Most researchers agree that activation of both languages in the bilingual brain occurs in a non-selective manner (e.g., Kroll, Bobb, & Wodniecka, 2006; Marian & Spivey, 2003),

1. This is not to say that there are not language-specific EFs involved in language control. There is also evidence for language specific outcomes in language switching (e.g. Gollan, Sandoval, & Salmon, 2011; Ivanova, Murillo, Montoya, & Gollan, forthcoming)

even when the context involves only one language (e.g., Colomé, 2001). Despite this, utterances and even single words are rarely spoken in the unintended language (e.g., Gollan, Sandoval, & Salmon, 2011; Poulisse, 1999). These findings suggest that some kind of control is exerted to select the appropriate language in any given context. Some researchers have argued that inhibitory processes are necessary in order to ignore one language while attending to the other. Consider for example, the Inhibitory Control (IC; Green, 1998) model which states that each lexical concept is associated with a lemma (i.e. word) in a specific language; these lemmas are all in turn associated with a tag that identifies language membership (e.g. French word vs. English word). Having these language tags allows language schemas (i.e. a cognitive framework for which to organize linguistic input) to help select the appropriate language by inhibiting the lemmas with inappropriate language tags. According to this model, two types of inhibition are involved, one at the level of the concept-to-lemma and the other at the level of the whole language.

The IC model can predict several findings from language switching studies, including the seminal work of Meuter & Allport (1999) and others (e.g., Costa & Santesteban, 2004; Linck, Kroll, & Sunderman, 2009; Philipp, Gade, & Koch, 2007; Philipp & Koch, 2009). During a language switch, the IC model suggests that all lemmas of the previously activated language schema are inhibited in order to reactivate the current language schema. Thus, a language switch requires reactive inhibition. Importantly, the IC model predicts asymmetric switch costs, which is the finding that it takes longer to switch to the dominant (L1) than to the non-dominant (L2) language (e.g., Costa & Santesteban, 2004). When switching from an L2 to an L1 response, much effort is required to overcome inhibition of the dominant L1 that took place on the previous trial. On the other hand, when switching from L1 to L2, less inhibition needs to be overcome because the L2 did not need to be inhibited as much on the previous trial. Furthermore, the IC model can be applied to both speech production and word recognition.

Other inhibitory models focus specifically on word recognition. Consider the bilingual interactive activation (BIA) model, in which a common lexicon contains words of both languages and inhibitory processes are deployed at the lexical level (Dijkstra & Van Heuven, 2002). This model suggests that activation of a single word at the lexical level also activates the language node (i.e., similar to the language tag in the IC model) of the corresponding language. When either the L1 or L2 language node receives enough activation it inhibits the opposite language globally (Dijkstra & Van Heuven, 2002). Joint activation within word recognition has not only been found at the lexical and whole language level, but has also been demonstrated at the sub-lexical level (Schwartz, Kroll, & Diaz, 2007; Timmer et al., 2014). For example, the same phoneme (e.g., /w/) in English and Dutch can have different phonetic characteristics. The position of the tongue for /w/ is different in Dutch (i.e., labiodental) than in English (i.e., bilabial). While the pronunciation is slightly different in each language, they are represented by the same phoneme and thus prime each other; it appears therefore that sub-lexical phonological information is also stored together (Timmer et al., 2014). These findings suggest that joint-activation of multiple languages occurs at multiple levels, including the lexical level, the whole language level, and the sub-lexical level. Based on these findings it seems likely that inhibitory control processes take place at multiple levels simultaneously.

In addition to control mechanisms operating at different levels, evidence suggests that the locus of (language) control varies as a function of the environmental context (Green, 1986, 1998; Green & Abutalebi, 2013; Kroll et al., 2006). Psycho-social and linguistic research has suggested that many factors, collectively known as *language mode*, influence the relative activation levels of each language. For example, language activation can be influenced by the relative presence of each language in a specific environment or by the interlocutor with whom one is interacting (e.g., Grosjean, 2001, 2008; Kootstra, Van Hell, & Dijkstra, 2010). Green and Abutalebi (2013) suggest that three bilingual contexts can be distinguished: (1) single-language contexts in which each language is used in a separate environment, (2) dual-language contexts in which one must switch between languages in a single environment depending on with whom they are speaking, and (3) dense code-switching contexts in which bilinguals intermix both of their languages within a single sentence. Green and Abutalebi (2013) argue that each of these interactional contexts (i.e. single language, dual language, dense code-switching) place different demands on control processes. They distinguish among eight domain-general cognitive control processes: goal maintenance, interference control (conflict monitoring and interference suppression), salient cue detection, selective response inhibition, task disengagement, task engagement, and opportunistic planning. The assumption is that the environmental context in which a bilingual resides places different demands on each of these control processes. For example, dual-language context bilinguals must actively maintain the goal of not allowing the irrelevant language to intrude when speaking to a particular person. This also holds for single-language contexts, but with weaker activation of the non-target language. Dense code-switchers on the other hand do not have this issue because intrusions from the other language are usually welcome and understood by the recipient.[2] Therefore, dual language bilinguals have the most practice with goal maintenance and interference suppression whereas dense code switchers have the least, a difference that may generalize to performance on

2. It is possible that dense code switchers do not require language control at all because switches might be driven by lexical access or primed by the interlocutor. We thank Iva Ivanova for raising this possibility. However, it is also possible that continually switching between languages enhances attentional control mechanisms.

tasks that tap into these processes. On the other hand, continually switching between languages might enhance attentional control mechanisms and this could generalize to performance differences on tasks that measure cognitive control. Verreyt et al. (2016) have indeed shown that conflict resolution performance differs between dense code switchers and other types of bilinguals.

Some researchers have begun to explore the influence of different language contexts on performance by modifying conflict resolution tasks. Wu and Thierry (2013) used a non-verbal arrow flanker task (Eriksen & Eriksen, 1974) and interleaved irrelevant words between the trials. During the flanker task, participants are required to press one of two buttons in response to a central arrowhead while ignoring the flanking arrows. Sometimes the flanking arrows are congruent with the central arrow (e.g. <<<) and sometimes the arrows are incongruent with the central arrow (e.g. <><). Irrelevant words were interleaved in between the presentation of these critical trials. Bilingual participants were told to ignore the irrelevant words and simply respond to the direction of the central arrow. The words served as a way of manipulating single or dual language contexts. In one block of trials, words from both languages were interleaved, and in another block of trials, words from only one of the languages were interleaved between the trials. Even though these words were irrelevant to the task, they nonetheless significantly influenced how bilinguals performed. Bilinguals were more accurate on incongruent trials within the mixed-language context than in the single language context. Thus, there are not only different types of inhibitory control when switching between languages, but the context in which a bilingual resides places different demands on the control processes, which further highlights the complexity of the bilingual advantage on executive function tasks.

3. Executive functions

Executive functions (EFs) refer to a broad range of general control mechanisms used to regulate our thoughts and interact efficiently within our constantly changing environments. In this sense, EF is multi-faceted (Friedman et al., 2006; Ito et al., 2015; Miyake et al., 2000). For example, Miyake et al. (2000) made a distinction between three major components of EF: inhibition, updating/monitoring, and shifting. Different conflict tasks that are used to examine performance differences between monolinguals and bilinguals depend to a different degree on each of these mechanisms. For example, according to Miyake et al. (2000), inhibition is likely the most important component in the anti-saccade task (Hallett, 1978), where one is required to make eye-movements toward the opposite side of a stimulus, whereas updating/monitoring and shifting are of less importance. On the other hand, during task-switching the most important mechanism to consider would be what Miyake calls shifting. Given that different tasks tap into different mechanisms, it is not surprising that correlations between these different tasks have often been reported to be weak (Miyake et al., 2000, Friedman et al., 2008, 2011). Furthermore, when different tasks are used, it is again not surprising that sometimes a bilingual advantage is reported (e.g. Prior & MacWhinney, 2010), and that sometimes it is not (Paap & Greenberg, 2013). It is quite likely that not all EF components contribute equally to performance and that context plays an important role in moderating these effects. But even within specific subcomponents of EF, a further distinction is often required. For example, there are different forms of inhibition: proactive and reactive (Colzato et al., 2008). Disentangling the contributions of proactive and reactive forms of cognitive control is essential to understanding cognition (Braver, 2012).

Proactive control is implemented in anticipation of upcoming task-demands (Braver, Gray, Burgess, 2007; Braver, 2012). This type of control is beneficial when attention needs to be sustained for a period of time and upcoming cognitive load can be predicted. In other words, proactive control is the endogenous control that is adopted and must be actively maintained to prevent interference from potential conflicting situations in the future. For example, if mostly incongruent trials are encountered during a flanker task (Eriksen & Eriksen, 1976), proactive control might be used to slow down overall response times in order to be prepared for potentially conflicting stimuli in the future. If mostly congruent trials are performed on the other hand, proactive control might work by speeding up overall performance in order to identify most of the targets. This type of control can also be observed in language switching, in which the language that is not being used is inhibited at a global level, thereby speeding up overall production of the language used most and slowing down production of the language used least (Costa & Santesteban, 2004; Dijkstra & Van Heuven, 2002). In this sense, proactive control is strongly related to the concept of goal maintenance of a language in the adaptive control hypothesis (Green & Abutalebi, 2013). Because bilinguals constantly encounter conflict in their environments in the form of jointly-activated languages, it may be beneficial for them to rely heavily on proactive control in order to optimize performance over time. The extent to which proactive control will be beneficial likely relies to a large extent on the interactional context of the environment in which the bilingual resides. In a single-language context, where one language is spoken in one environment (e.g., home) and another language is spoken in a separate environment (e.g., work), there is no need for proactive control. In a dual-language context on the other hand, language switching does occur, and proactive control is likely beneficial because one can usually predict which language will be spoken more often. Proactive control is not likely beneficial in a dense code-switching environment because there are no rules about which language to speak and it is completely unpredictable. Thus, proactive control is more likely to develop in dual-language contexts than in other interactional contexts, and individuals that grow up in these environments might experience enhanced proactive control on conflict tasks in which one type of trial is experienced more often than others. For example, dual language context bilinguals might be more efficient than other types of bilinguals at using proactive control when 80% of trials are incongruent but only 20% are congruent because frequency of trial type can likely be detected. These individuals might also be quicker to adapt to a new context. For example, if now 20% of trials are incongruent and 80% of trials are congruent. One can imagine an English-Hindi bilingual living in Toronto who speaks mostly English because of her usual environment, but when her grandmother visits for a week, this environmental context changes and Hindi becomes the dominant language spoken, creating more conflict.

Proactive control can be very demanding given that goals must be continually maintained in working memory, but this might be why some studies have shown working memory advantages for bilinguals compared to matched monolinguals (Bialystok, Poarch, Luo, & Craik, 2014; Biedron & Szczepaniak, 2012; Soliman, 2014). Practice with this type of control may develop working memory capacity over time. This suggests that proactive control and working memory processes might be tightly interconnected. On the other hand, it may be too resource demanding for bilinguals to rely too heavily on proactive control, not leaving enough resources to perform other important cognitive tasks. If this is the case, it would be beneficial for bilinguals to rely more on a form of control that relies on reactive on-the-fly adjustments in performance.

Reactive control is the online adjustment in control that is implemented in response to a particular, usually conflicting environmental stimulus (Braver, Gray, Burgess, 2007; but see Compton et al., 2012 for non-conflict trials driving reactive control). It is a form of control that adjusts performance as a correction to an event that is different than what was expected. Rather than a sustained (proactive) control process, an individual might rely more heavily on the stimulus to drive a reactive control process that reactivates goal demands on-the-fly. This is especially beneficial when predictions of upcoming cognitive load cannot be made based on the context and trial-by-trial adjustments need to be made. For example, if 50% congruent and 50% incongruent trials appear randomly within a block, reliance on more reactive control and less proactive control might be beneficial because it is not possible to predict what is going to appear next. If bilinguals are in an environment in which they are continually switching between both languages, it might be beneficial for them to rely more heavily on reactive control, and this might generalize to enhanced reactive control on conflict tasks in which there are lots of unpredictable switches between trial types, leading to a performance advantage over monolinguals. It is noteworthy to point out here that more general attentional mechanisms might also be important to consider when transitioning between reactive and proactive forms of control. Specifically, disengagement of attention from previous information might occur once reactive control (to resolve the unexpected conflict) has taken place and before the implementation of proactive control (more discussion on disengagement in the next section).

Whether or not the bilingual executive control advantage is influenced by reactive or proactive control is still uncertain, but a few studies have made some initial progress toward answering these questions. Recent studies by Morales and colleagues have used the AX version of the continuous performance test (Rosvold et al., 1956; AX-CPT) to assess differences in reactive and proactive control between monolinguals and bilinguals (Morales, Gómez-Ariza, & Bajo 2013; Morales et al., 2015). The AX-CPT is a task in which participants are required to respond "yes" to the probe letter X whenever it is preceded by the cue letter A (Figure 1). In all other combinations of cues and probes, participants are told to respond "no". Target trials (AX) appear with high frequency (70% of all trials) throughout the experiment to prime a prepotent response when the probe appears. Three other trial types are presented on the remaining 30% of trials, randomly intermixed within the same block. Ten percent of trials are AY trials in which the cue is an A and the probe is a non-target (e.g. Y). In this case, participants are primed (via the A cue) to predict that an X will appear on the probe and hence require a "yes" response. Maintenance of this prediction in working memory requires proactive control. Errors on these trials (i.e. making a "yes" response when the correct answer is to say "no") are thus errors due to the influence of proactive control. BX trials are presented on 10% of trials and they represent adjustments in reactive control. On these trials the cue is a non-A letter but the probe is the letter X that is usually associated with a preceding A. Proactive control on these trials will lead participants to make the correct "no" response because participants will expect that the cue-probe combination will be a non-target. However, because the letter X is usually preceded by the letter A, participants will need to stop themselves from responding to the predominant "yes" response, and this requires reactive control. Thus, errors on the BX trials are failures in reactive control. The last 10% of trials belong to the BY trials for which there is no bias with respect to cue or probe, and hence serve as a control.

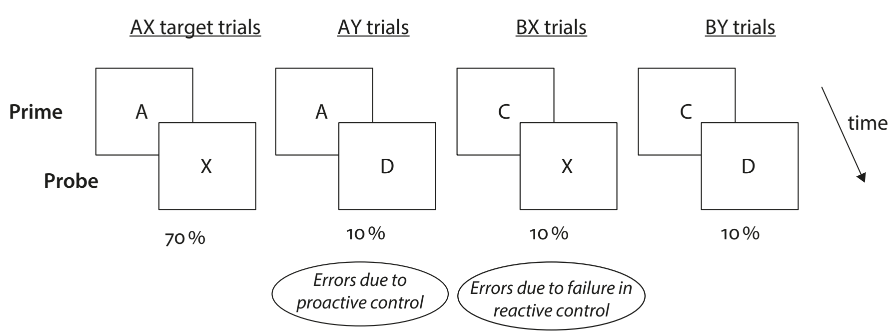

Figure 1. Example trials during the AX version of the continuous performance test (AX-CPT)

Morales, Gómez-Ariza, & Bajo (2013) were the first to use the AX-CPT to explore the role of proactive and reactive control mechanisms in producing different patterns of performance between monolingual and bilingual participants. They found that all participants were more accurate on the BX and BY trials than they were on the AY trials, but that bilinguals were significantly more accurate than monolinguals on the AY trials. This suggests that all participants were using the context to predict what the probe would be (i.e. using proactive control), but that bilinguals were less reliant on proactive control than were monolinguals. The authors also found that bilinguals were slower than monolinguals to make these judgments. They interpreted the latter finding as suggesting that bilinguals were also more reliant on reactive control to some extent because reactive control relies on the stimulus being processed before any control can be implemented. Thus, if more reactive control is being relied upon, it should take longer to respond to those targets. To rule out a simple speed-accuracy tradeoff, the authors examined delta plots for the conflict effects and RT distributions. Delta plots represent the extent to which an experimental effect (in this case, the difference between AY and BY trials) differs as a function of RT length (De Jong, Liang, & Lauber, 1994; Ridderinkhof, 2002). They found that bilinguals showed less interference at longer RTs than did monolinguals. Given these data, the authors concluded that, compared to monolinguals, bilinguals rely more on reactive control and less on proactive control to achieve optimal performance. Thus, it is not a question of whether proactive or reactive control alone underlies the difference in performance between monolinguals and bilinguals, but rather, it is the dynamic interplay of these two forms of control that lead to a performance enhancement.

A subsequent electrophysiological study supported and extended these findings by having participants perform the AX-CPT while electroencephalography (EEG) was recorded (Morales, Yudes, Gómez-Ariza, & Bajo, 2015). First, bilinguals performed better than monolinguals on the AY trials, suggesting that bilinguals were less reliant on proactive control. Furthermore, the combination of event-related potential (ERP) and behavioural data suggested that only monolinguals that relied less on engagement of proactive control could perform on par with bilinguals on AY trials. Bilinguals also showed larger N2 amplitudes in response to the AY trials. Larger N2 amplitudes are associated with more conflict detection (Yeung & Cohen, 2006; Nieuwenhuis, Yeung, Van Den Wildenberg, & Ridderinkhof, 2003), and thus reflect more reactive control processing. Finally, bilinguals showed smaller error-related negativities (ERNs) than monolinguals. The ERN is a response-locked ERP component that is elicited in response to errors, and this component is generally believed to reflect a need for additional top-down control (Gehring, Liu, Orr, & Carp, 2012). Thus, the authors concluded that the data support the notion that both proactive and reactive control mechanisms are contributing to the bilingual advantage, rather than simply one or the other.

Even though the AX-CPT task shows some promise for understanding how proactive and reactive forms of control operate across individuals, there are some important caveats that need to be considered regarding the interpretation of which trials assess proactive and which trials assess reactive control. We discussed how on AY trials, after the A cue is presented, proactive control will lead participants to make incorrect judgments when the non-X probe (e.g. Y) appears, but an alternative explanation involving priming and reactive control is still possible. The A cue might prime a prepotent response (because it is associated with a particular response on 70% of trials), and when the non-X probe appears, reactive inhibition of the prepotent response is required. Thus, errors on these trials could result from underdeveloped reactive control. In contrast, we discussed how errors on BX trials reflect failures in reactive control because the X probe is usually preceded by an A and reactive control is needed to stop the associated prepotent response. But *good* proactive control on these trials points to a *correct* response, so these trials require both forms of control. Thus, it appears that trials in the AX-CPT task, like most EF tasks, are not process pure and caution should be taken when interpreting findings.

It is important to consider what attentional mechanisms might be driving transitions between proactive and reactive forms of control. Disengagement of attention from the previous trial in order to attend to the current trial is one potential mechanism. For example, if reactive control is used to deal with an unexpected conflicting stimulus, disengagement of attention from this trial is required before the next stimulus is processed and before proactive control can be implemented. Thus, disengagement is an attentional process that guides behaviour across different forms of control.

4. Disengagement of attention

There are reasons to believe that speed of disengagement of attention is contributing significantly to bilingual cognitive performance advantages, yet it remains largely unexplored. Disengagement of attention might help to explain why bilingual infants outperform monolingual infants on tasks that measure EF (Kovács & Mehler, 2009; Pons, Bosch, & Lewkowicz, 2015; Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012; Weikum et al. 2007), whereas inhibitory accounts fall short. The idea put forth by inhibitory accounts is that bilinguals have practice inhibiting the jointly-activated irrelevant language in order to attend to and select the relevant language in any given context; this contributes to generalized inhibitory control processes that lead to better performance on general conflict tasks. However, preverbal bilingual infants by definition do not have defined language representations and it is not possible for one language to be inhibited in order to select the other. Preverbal bilingual infants need to somehow learn that any given object can be represented by two words and that this depends not only on the environmental context, but also on the interlocutor with whom the infant is interacting. Thus, it would be adaptive for these infants to pay attention to everything and learn to rapidly disengage from this information once it is processed.

The disengagement hypothesis can shed light on several findings from conflict resolution tasks. Consider the flanker paradigm (Eriksen & Eriksen, 1974) that is used in much of the research examining differences in performance between bilinguals and monolinguals. Performance is generally better on congruent trials (e.g. <<<) than on incongruent trials (e.g. <><), and bilinguals often outperform monolinguals on these tasks (Costa, Hernández, & Sebastián-Gallés, 2008; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009). Many researchers have attributed the latter finding to superior inhibitory processes for bilinguals compared to matched monolinguals (Tao, Marzecova, Taft, Asanowicz, & Wodniecka, 2011; Marzecova, Asanowicz, Kriva, & Wodniecka, 2012). Enhanced inhibitory control processes as a result of lifelong experience with multiple languages could indeed help bilinguals perform better on incongruent trials in which the irrelevant arrows must be inhibited. Problematic to this logic is the finding that bilinguals do not simply perform better than monolinguals on the incongruent trials, but also outperform them on the congruent trials in which there is no need for inhibition (see Hilchey & Klein, 2011 for a review). It is likely that bilinguals outperform monolinguals because of other reasons. Hilchey and Klein (2011) suggested that superior conflict monitoring (Botvinick et al., 2001), or trial-by-trial adjustments in top-down control, might explain global performance advantages for bilinguals over monolinguals. Alternatively, or in addition, bilinguals might have quicker access to episodic retrieval of task-relevant rules. When a flanker trial appears, task-relevant information like task instructions and which response button corresponds to which side (i.e., stimulus-response mappings) needs to be retrieved from memory. If bilinguals are faster at retrieving some of this information from memory, this would lead to benefits in processing both congruent and incongruent trials. Another possibility, which we will show has both theoretical and empirical support, is that bilinguals might be better than monolinguals at disengaging attention from one trial in order to perform the next. If attention can be rapidly disengaged from every trial, this would likely facilitate performance on the following trials, effectively leading to a performance advantage on both congruent and incongruent trials. Given these equally plausible alternative explanations for the bilingual advantage on the flanker task, it becomes impossible to conclude that inhibition is the only mechanism driving the bilingual advantage on this task.

The disengagement hypothesis is compatible with the disengagement control processes that Green and Abutalebi (2013) briefly touched upon in their adaptive control hypothesis paper, and evidence from other work is beginning to emerge. Mishra, Hilchey, Singh, & Klein (2012) recently used an inhibition of return (IOR; Posner & Cohen, 1984) paradigm to show that high proficiency bilinguals were better able than low proficiency bilinguals to rapidly disengage attention from an irrelevant distractor. In a typical IOR paradigm, participants are required to make a left or a right key press in response to a target that appears within a box on the left or the right side of the screen. Critically, before the target appears, either the left or the right box is flashed briefly. Participants are told to ignore the flashed box cue because it is unpredictive of which side the target will appear. When the cue-to-target interval is *short*, response times are *faster* when the cue and target appear on the same side compared to when the cue and target appear on the opposite side. However, when the cue-to-target interval is *long*, response times are *slower* when the cue and target appear on the same side compared to when the cue and target appear on the opposite side (i.e. the inhibition of return effect is observed). This switch from facilitation to inhibition is believed to be the result of how much time is allowed for the participant to disengage attention from the irrelevant cue (Klein, 2000). When not a lot of time is available to disengage attention and the target appears on the same side as the distractor, facilitation is observed because resources are still devoted to processing this location. When more time is available to disengage attention and the target appears on the same side as the distractor, performance is slowed because it takes time to fully re-engage attention to where attention was just withdrawn. Mishra, Hilchey, Singh, & Klein (2012) found that high proficiency bilinguals were not only faster overall than low proficiency bilinguals on this task, but that they showed an IOR effect at shorter cue-to-stimulus intervals. This suggests that they were able to disengage attention more rapidly than their low proficiency counterparts. Consistent with this, Colzato et al. (2008) found that bilinguals had larger IOR effects than monolinguals, a finding that would be expected if monolinguals experienced facilitation at more of the cue-to-stimulus intervals than bilinguals because of their slower disengagement of attention.

Evidence from other studies using different paradigms supports the notion that bilinguals are better able to disengage attention, even though the authors of these studies do not interpret their findings in this way.[3] For example, Blumenfeld and Marian (2011) used a paradigm in which participants saw four pictures in four quadrants and had to identify with a button press which of the pictures was presented auditorily. Some of the non-target pictures were phonologically similar to the target, and thus attracted attention. Following this, using the same four quadrants, participants responded to the location of a greyed-out asterisk among three other black asterisks. They found that monolinguals were more influenced by the location of the distractors on the previous picture display than were bilinguals. These findings are consistent with

3. Nor did Colzato et al. (2008) in the IOR study above.

a model in which bilinguals are better able to disengage attentional resources from previous information.

The disengagement hypothesis is also consistent with findings showing that bilinguals are faster than monolinguals during task-switching (Gold et al., 2013; Prior & MacWhinney, 2010). Switching between tasks inherently involves engaging attention toward the current task and disengaging attention from the previous task. If bilinguals are better able to rapidly disengage, this should facilitate performance on the following trial.

It is also possible to explain the bilingual advantage in terms of disengagement of attention on the AX-CPT task described earlier. Recall that bilinguals were more accurate and showed less interference at longer RTs than monolinguals on AY trials, where the A would serve as a cue that an X will likely appear next. In this case, errors on these trials might be due to proactive control. Another interpretation is that after the A appears, bilinguals rapidly disengage attention from it in order to respond in an unbiased manner to the following trial that appears. This would effectively lead to the same result: bilinguals being more accurate and showing less interference at longer RTs than monolinguals on the following trials. It is important to note that we do not claim that disengagement of attention is the only mechanism contributing to differences between monolinguals and bilinguals on these tasks, but rather, that it might be contributing; it is likely that an array of processes are involved in contributing to the bilingual advantage across different tasks.

Different types of analyses on conflict resolution tasks may also be revealing for examination of disengagement processes. During the flanker task, participants encounter two different types of trials: incongruent (I) and congruent (C). However, classifying trials as simply I and C does not take into account the influence of previous trial congruency and as such, collapses across potentially important information. If previous trial information is taken into account, then there are four trial types that can be encountered: current congruent trials in which the previous trial was congruent (cC), current congruent trials in which the previous trial was incongruent (iC), current incongruent trials in which the previous trial was incongruent (iI), and current incongruent trials in which the previous trial was congruent (cI) (Figure 2). This allows us to determine the extent to which previous trial congruency influences current trial performance, and this adjustment in response strategy has been shown to be critical in studying cognitive control (Botvinick et al., 2001; Gratton, Coles, & Donchin, 1992; Desender, Van Opstal, & Van den Bussche, 2014; Jiménez & Méndez, 2013; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; Schmidt, & Weissman, 2014; Ullsperger, Bylsma, & Botvinick, 2005; Wang et al., 2015; Weissman et al., 2015; see Egner, 2014 for a review). Furthermore, there is reason to believe that smaller adjustments based on previous trial congruency are associated with more practice (Mayr & Awe, 2009; van Steenbergen et al., 2015), and one might expect bilinguals to show smaller adjustments if they have generalized practice disengaging attention from previous information. Recent evidence using this type of analysis on a typical flanker task suggests that this is in fact the case (Grundy, Chung-Fat-Yim, Friesen, Mak, & Bialystok, under review). Grundy, Chung-Fat-Yim, Friesen, Mak, & Bialystok (under review) showed that bilinguals had smaller sequential congruency effects (SCEs) than monolinguals; SCEs use the four different trial types (cC, iC, iC, iI) to provide a single index of how much the previous trial influences current trial performance (Figure 2; e.g. Weissman et al., 2015). This suggests that bilinguals show more rapid disengagement of attention than monolinguals on the flanker task.

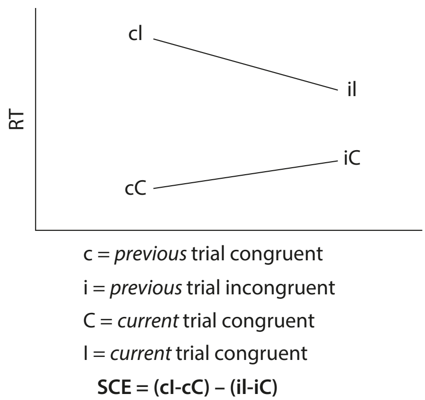

Figure 2. Examination of different trials types during the flanker task when previous trial congruency is taken into account. SCE = sequential congruency effect. Calculation of the SCE allows one to examine a more sensitive measure of performance than the typical flanker effect (incongruent – congruent)

One paradigm that may be well-suited to examine disengagement processes is the bivalency effect paradigm (Grundy et al., 2013; Grundy & Shedden, 2014a, 2014b; Meier, Woodward, Rey-Mermet, & Graf, 2009; Meier & Rey-Mermet, 2012; Rey-Mermet & Meier, 2012a, 2012b; Rey-Mermet, Koenig, & Meier, 2013; Woodward, Meier, Tipper, & Graf, 2003; Woodward, Metzak, Meier, & Holroyd, 2008). This paradigm is particularly useful if one would like to examine the influence of disengagement processes without confounding results with additional processes present in most conflict paradigms. For example, during the flanker task, there are many conflict trials (i.e. when the relevant central arrow and the irrelevant flanking arrows are incongruent). The same is true of the Stroop task (Stroop, 1935), where the two features are the relevant ink colour and the irrelevant word. Thus, examining disengagement processes on trials following conflict becomes difficult because many of the subsequent trials also require conflict resolution to take place. In the bivalency effect paradigm, each stimulus only has one feature and cues a single task. In a typical laboratory experiment, participants switch between three simple tasks (Figure 3). In one block of trials, all of the stimuli are univalent (associated with only one task). In another block of trials, occasional conflicting (bivalent – cueing two tasks) stimuli appear amongst mostly univalent stimuli. This allows one to examine the influence of conflicting (bivalent) trials on subsequent univalent trial performance to get a measure of disengagement processes. The critical comparison is between reaction times (RTs) to univalent trials that appear in purely univalent trial blocks and univalent trials that appear in a block amongst occasional bivalent stimuli. The typical finding is such that a robust post-conflict slowing effect is observed on trials that appear amongst occasional bivalent stimuli compared to trials that appear in pure blocks (Meier, Woodward, Rey-Mermet, & Graf, 2009). With this paradigm, we examined the influence of previous trial conflict on subsequent trial performance between monolingual and bilingual children. Pilot data from fifteen monolingual and fifteen bilingual 7-year old children performing this simple task-switching experiment provide preliminary support for the bilingual disengagement hypothesis. Bilinguals appear to be showing a smaller and shorter-lived post-conflict slowing effect than monolinguals. This suggests that bilinguals are better able to rapidly disengage attention from the previous conflicting (bivalent) stimulus in order to perform optimally on subsequent univalent trials. We caution that this is still preliminary data and that more participants as well as a full set of statistical analyses are necessary before any firm conclusions can be made.

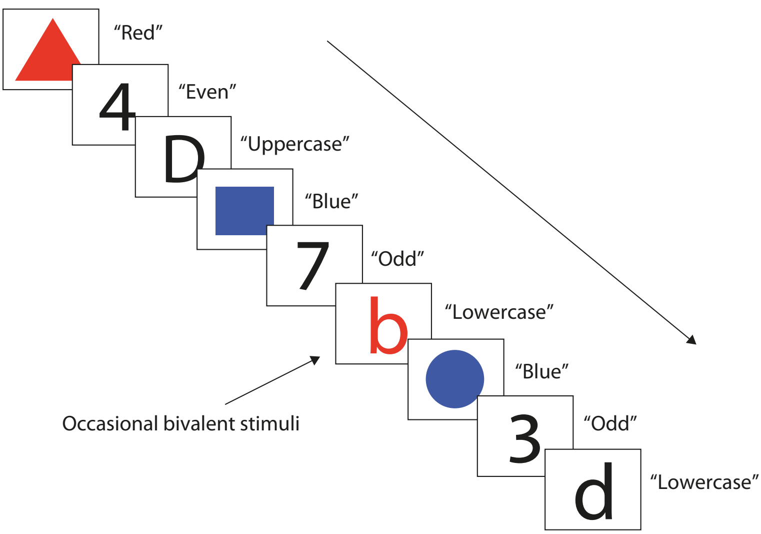

Figure 3. Example of a bivalent block in the bivalency effect paradigm. Performance on univalent trials within this block is compared to performance on univalent trials within a block of purely univalent stimuli. This is taken as a measure of post-conflict slowing and can examine critical disengagement of attention processes

5. Conclusions and future directions

We have highlighted the need for a more detailed evaluation of the bilingual performance advantage on conflict resolution tasks. Many general tasks such as flanker, Stroop, and Simon (Simon, 1969) have provided us with a great start for a complex research program, but it appears that multiple cognitive processes underlie the bilingual advantage, and these tasks cannot always isolate one mechanism over another in contributing to the performance boost, at least not without more complex analyses. Determining the extent to which each of these cognitive processes contributes to bilingual performance and how these processes work together is an exciting research program for the future.

Using tasks that can distinguish between particular mechanisms, such as (for example) the contributions of proactive and reactive control, are a good start toward identifying the dynamic processes involved in the executive function advantages that bilinguals have over monolinguals. Furthermore, it is important to remember that even when tasks are designed to examine a small subset of processes, it is often still possible that other mechanisms and processes are contributing, such as priming and speed of episodic retrieval of memory representations.

More complex analyses may sometimes be necessary in order to reveal subtle performance differences that exist between individuals that differ in their language experiences. For example, efficiency scores (Christie, & Klein, 1995; Townsend & Ashby, 1983) that incorporate both RT and accuracy together in a single measure to combat speed-accuracy tradeoffs, reveal important processing differences between groups when RTs and accuracy alone do not (Blumenfeld & Marian, 2014). Sequential congruency effect analyses also reveal important attentional disengagement differences when regular flanker analyses do not (Grundy, Chung-Fat-Yim, Friesen, Mak, & Bialystok, under review).

We suggest that rapid disengagement of attention from previous conflict may be a significant contributor to the bilingual advantage, and that a simple story involving only inhibitory mechanisms no longer provides the most complete picture. Performance differences between monolinguals and bilinguals on many of the tasks used in the literature are subtle and more sensitive measures of cognitive control are needed. Finally, future studies should collect more exhaustive linguistic background information given that many linguistic factors, such as code-switching frequency and different socio-linguistic environments can impact critical cognitive outcomes.

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