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A network-level analysis of cognitive flexibility reveals a differential influence of the anterior cingulate cortex in bilinguals versus monolinguals

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Mounting evidence suggests that bilingual development may change the brain in a way that gives rise to differences in non-linguistic cognitive functioning; however, only a limited number of studies have investigated the mechanism by which bilingualism shapes the brain. The current study used a network-level analysis to investigate differences in the mechanisms by which bilinguals and monolinguals flexibly adapt their neural networks in the face of novel task demands. Three competing hypotheses concerning differences in network-level adaptation were examined using Dynamic Causal Modeling of data from 15 bilinguals and 14 monolinguals who performed a Rapid Instructed Task Learning paradigm. The results demonstrated that the best-fitting model for the data from both groups specified that novel task ex- ecution is accomplished through a modulation of the influence of the anterior cingulate cortex (ACC) on the dorsolateral prefrontal cortex (DLPFC) and on the striatum. Further examination of the best-fitting model revealed that ACC activity increased DLPFC and striatal activity in bilinguals but decreased activity in these regions in monolinguals. Interestingly, an increased positive connection between the ACC and striatum was associated with decreased accuracy across groups. Taken together, the results suggest that regardless of language experience, the ACC plays a critical role in cognitive flexibility, but the exact influence of the ACC on other primary control regions seems to be dependent on language experience. When paired with the behavioral results, these results suggest that bilinguals and monolinguals may employ different neurocognitive mechanisms for conflict monitoring to flexibly adapt to novel situations.

1. Introduction

Previous research has demonstrated that bilinguals and monolinguals demonstrate significantly different executive functioning behavioral task performance, including tasks that require cognitive flexibility. Several of those studies have concluded that bilinguals show an advantage in executive functioning task performance (e.g., Bialystok et al., 2004; Carlson and Meltzoff, 2008; Prior and MacWhinney, 2009). Differences in executive functioning task performance in individuals who develop bilingually (i.e., individuals who were too young to self-select into a specific language environment) compared to monolinguals suggest that some aspect of bilingual development may "train the brain" in a way that results in generalized differences in executive functioning (Buchweitz and Prat, 2013; Kovelman et al., 2008; Stocco et al., 2014). Therefore, identifying the neural mechanism(s) of such behavioral differences could have important implications for our understanding of the (1) training of executive functioning, (2) nature of individual differences in executive functioning, and (3) impact that bilingual development has on the mind and brain. The current study examined the neural basis of differences in executive functioning in bilinguals and monolinguals by examin- ing properties of brain functioning at the network level.

While a number of behavioral experiments have cataloged differences in cognitive abilities between bilinguals and monolinguals, relatively few studies have investigated the neural bases of these differences. Those who have investigated these differences have implicated a variety of brain regions (e.g., the prefrontal cortex, anterior cingulate cortex, and basal ganglia), each of which is associated with some aspect of executive functioning (e.g., Abutalebi et al., 2012; Garbin et al., 2010; Gold et al., 2013; Stocco and Prat, 2014). The heterogeneity of these results could be due to the different tasks used in these studies. However, given

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that the tasks used require some of the same components of executive functioning, and therefore some of the same brain regions, the heterogeneity of the results might be due to the fact that the critical difference between bilinguals and monolinguals is not localized within a single region but can be traced to differences in the dynamics within a network of regions. Recent neuroimaging research on the neural basis of individual differences in cognition, for example, has demonstrated that dynamic, network-level characterizations of brain function better explain brain-behavior relations than do more static, focal descriptions (e.g., Prat et al., 2007; Prat and Just, 2011). Therefore, we adopted a network-oriented approach to account for how each of these regions interacts with one another and with other key regions in the distributed executive functioning network.

To fully comprehend the biological basis of executive func- tioning differences in bilinguals, it is critical to (1) understand the characteristics of the executive functioning network in the general population and how they relate to behavior; and (2) understand the network connectivity *differences* associated with executive functioning in bilinguals and monolinguals. Specifically, by using methods for assessing the flow of information throughout the network, one can develop and test separate models of how ex- ecutive processes might be achieved at the network-level. To do so, the current study employed Dynamic Causal Modeling (DCM) to test different models of how brain regions that are central to executive functioning interact during a task that requires executive processes. The goal of generating these models is to examine the possibility that differences in network-level functioning may un- derlie the behavioral differences observed between bilingual and monolingual individuals.

To investigate the executive functioning network, one must first define the nodes of the network and then determine how and when they interact. This is not a trivial process, as the specific components implicated and the nature of their interaction may vary considerably as a function of the type of task being executed. Critically, it has been argued that executive functioning is a broad construct with multiple potential component mechanisms (e.g., Miyake et al., 2000; O'Reilly, 2006; Tranel et al., 1994), and therefore, it is important to define specific components of, or focus on specific aspects of, executive functioning to consider its neural constituents. Investigations of executive functioning have used at least two different approaches to specify the focus: a *divide-and-conquer approach* which examines specific, separate components of executive functioning (e.g., Miyake et al., 2000) and a *functio- nalistic approach* which examines overarching goals of executive functioning (Cole et al., 2013). One advantage of the functionalistic approach is that it allows one to explore complex tasks that may require many facets of executive processing in parallel. Another crucial advantage is that it employs tasks that are arguably more generalizable to real-world scenarios (e.g., Stocco and Prat, 2014). For these reasons, the current research chose a functionalistic approach, examining a particular goal of executive functioning, which involves several components of executive functioning, ra- ther than investigating separate, specific components of executive functioning.

One of the primary purposes of executive functioning is to allow for the adaptation of behavior that characterizes human cognitive flexibility. Such flexibility is observed when an individual reconfigures his or her behavior to adapt to a novel situation or to make a non-automatic response. One circumstance in which cognitive flexibility is needed is during the execution of novel tasks. Such cognitive flexibility often requires several components of executive functioning such as switching (e.g., to a new rule), updating (e.g., changing the goal structure to a new task), inhibiting (e.g., resisting interference from competing rules or stimuli), conflict monitoring (e.g., monitoring response conflict), and maintaining the task goal. Importantly, these aspects of cognitive flexibility are also involved in language control and according to the adaptive control hypothesis, flexibly adapt to context-relevant demands (Green and Abutalebi, 2013). Thus, flexibility is a challenge that bilinguals frequently face during language processing, as selecting and combining linguistic rules based on the dynami- cally changing "target language" is often a necessity (Buchweitz and Prat, 2013; Stocco et al., 2014; Stocco and Prat, 2014). Given the importance of cognitive flexibility in general, as well as in language processing and control in bilinguals, the current research focused on the characteristics of the neural network involved in flexibly adapting behavior to execute a novel task. Through the examination of previous research on the neuroscience of cognitive flexibility in both the general population and in bilinguals speci- fically, we discuss potential neural mechanisms that may underpin differences in cognitive flexibility such as those observed in in- dividuals who develop bilingually.

1.1. The neural correlates of cognitive flexibility

When examining differences in cognitive flexibility between bilinguals and monolinguals from a network-level perspective, one crucial step is deciding which regions should be included in the network of interest. In this study, we decided to include regions that meet two criteria and were subsequently verified during the region of interest localization process. The first criterion is that the regions should have demonstrable involvement in tasks that re- quire the executive function goal of interest, cognitive flexibility. Second, the regions should be implicated in bilingual language control. These criteria were chosen to ensure the specificity of the identified network to cognitive flexibility mechanisms that, ac- cording to existing research, are differentially utilized by bilinguals and monolinguals.

One region that has been consistently implicated in executive functioning (e.g., cognitive flexibility) as well as in language con- trol is the dorsolateral prefrontal cortex (DLPFC). Specifically, the DLPFC appears to be associated with the formation and maintenance of internal rule and goal representations (Cole et al., 2010; Miller and Cohen, 2001; Wallis et al., 2001). Thus, when cognitive flexibility is needed to execute a novel task, the DLPFC is central for such adaptation (i.e., to aid in the maintenance of task goal/instructions). For instance, one study investigated differences in cognitive flexibility in younger and older bilinguals and monolinguals using a task-switching paradigm (Gold et al., 2013). The authors reported a smaller switch-cost in reaction times in bilinguals (i.e., the difference between switch and non-switch condi- tions, with bilinguals exhibiting faster performance during switch trials relative to age-matched monolinguals). Interestingly, 82% of the variance of this enhanced speed in the flexible adaptation of behavior in older bilinguals was accounted for by decreased BOLD response in a few regions, including the DLPFC and the anterior cingulate cortex (ACC).

Similarly, the DLPFC plays an important role in linguistic rule representation, with increased DLPFC activity being observed during tasks that involve language-switching conditions compared to non-switch conditions (Hernandez, 2009; Hernandez et al., 2001) in bilinguals. Thus, the DLPFC is a good candidate for driving the differences in cognitive flexibility observed between bilinguals and monolinguals (Bialystok et al., 2012), as it is involved both when an individual is presented with a novel or non-automatic task to execute and when he or she needs to modify a language response to match a dynamically changing target language.

A second region with notable involvement in both cognitive flexibility and language control in bilinguals is the ACC (e.g., Cole et al., 2010). Specifically, previous research has identified the ACC as a region involved in response conflict monitoring during novel, unpracticed, non-automatic trials (e.g., Abutalebi et al., 2012; Kerns et al., 2004). In addition, ACC activation has been found to predict subsequent improvements in behavior on tasks measuring cognitive control (Kerns et al., 2004). Investigations of differences in executive functioning between bilinguals and monolinguals have demonstrated decreased response conflict effects in the ACC in bilinguals, which suggests more efficient conflict monitoring (e.g., Abutalebi et al., 2012; Gold et al., 2013). In particular, in the previously discussed task-switching study comparing older bilinguals and age-matched monolinguals, a smaller neural switch-cost in the ACC was associated with a relatively smaller behavioral switch-cost in bilinguals (Gold et al., 2013). Consistently, during the Flanker task, Abutalebi et al. (2012) found a smaller conflict effect (i.e., the difference between conflict and non-conflict trials) in the ACC in bilinguals compared to monolinguals.

Similarly, the ACC has been implicated in monitoring response-based language conflict (e.g., van Heuven et al., 2008). For in- stance, during responses to interlingual homographs (i.e., words from two different languages that are spelled identically but have different meanings) in a lexical decision task, bilinguals exhibited increased ACC activity. Because homographs automatically activate two conflicting representations in two different languages, this effect is consistent with the established role of the ACC in mon- itoring response conflict. Thus, the ACC is another good candidate for driving the differences in cognitive flexibility observed be- tween bilinguals and monolinguals given the presence of ACC activity during response conflict in novel, non-automatic linguistic and non-linguistic tasks and the need for cognitive flexibility to adapt to that conflict.

A third region associated with cognitive flexibility and language control is the striatum, which has been associated with learning and rule application (Muhammad et al., 2006). For instance, dur- ing the execution of novel tasks, where cognitive flexibility is critical, the striatum seems to be responsible for controlling the selection of the appropriate task-specific variables and dynami- cally coordinating, or "gating", the information being sent from cortical processing centers to the prefrontal cortex (Frank et al., 2001; Frank, 2005; O'Reilly and Frank, 2006). Stocco and Prat (2014) used a Rapid Instructed Task Learning (RITL) paradigm to examine cognitive flexibility during the execution of novel in- structions in bilinguals and found that faster execution was asso- ciated with greater adaptability of the striatum in bilinguals. In other words, bilinguals exhibited greater activity in the striatum when executing novel tasks as compared to practiced tasks, which was associated with decreased cognitive costs for executing novel tasks.

Similarly, in language processing, the striatum appears to be involved in tracking the intended target language. This is evi- denced by a tendency to spontaneously switch back and forth between languages in bilingual individuals with striatal lesions (Abutalebi et al., 2000) and by the left striatum being the only region where lexical representations were separated according to "target language" in a cross-linguistic priming study (Crinion et al., 2006). Thus, the striatum is a good candidate for driving the dif- ferences in cognitive flexibility observed between bilinguals and monolinguals, as it is involved in both rule application and when shifting between multiple language representations.

A fourth region likely involved in the network responsible for cognitive flexibility is the posterior parietal cortex (PPC), which is associated with building or modifying representations of a task. For instance, when completing tasks involving arithmetic, PPC activity is proportional to the number of operations being calcu- lated (Danker and Anderson, 2007; Stocco and Anderson, 2008). Thus, the PPC appears to maintain a mental template for the ar- ithmetic task, communicating with the DLPFC and striatum to update information in working memory (Stocco et al., 2010, 2012).

Additionally, the PPC appears to play a role in language control in bilinguals, potentially aiding in response selection, as evidenced by an association between the inferior and superior parietal cortex and an asymmetric language switch cost (i.e., a larger switch cost when switching from the non-dominant second language to the dominant first language than vice versa; Wang et al., 2009). However, to our knowledge, there are no regional activation dif- ferences in the PPC between bilinguals and monolinguals in basic representation building and maintenance or in language control. Thus, the PPC does play a role in the neural network associated with cognitive flexibility and maintaining a mental template, but its role does not seem to be different in bilinguals and mono- linguals. Therefore, while the PPC is included in the network re- sponsible for cognitive flexibility discussed herein, it does not appear to be a candidate for driving differences in cognitive flex- ibility between bilinguals and monolinguals.

In summary, it is possible that at least three of the four brain regions indicated herein (i.e., the DLPFC, the ACC, and the striatum) could be implicated in the differential task performance between bilinguals and monolinguals in tasks requiring cognitive flexibility, as they comprise a circuit that is highly interactive. To determine their relative involvement in tasks that require re-configuring behavior flexibly, we specified multiple models of how information may flow through these regions, how activity in one region may influence the other regions, and how task demands may affect these patterns of connectivity.

1.2. Investigating network connectivity using Dynamic Causal Modeling (DCM)

Given that the goal of the current study was to investigate the properties of the executive functioning network, specifically dur- ing tasks requiring cognitive flexibility (e.g., during the execution of novel tasks), DCM (Friston et al., 2003) was identified as the most appropriate analysis. DCM investigates the directional causal influences that brain regions exert on each other, as well as the direct inputs from task components to regions of the brain, and the non-linear modulation of network connections by task com- ponents and by other brain regions. DCM requires that the ex- perimenter provide a model or models of how brain regions are connected using a network of directional connections. In addition to computing indices of effective and modulatory connectivity, DCM implements Bayesian methods to examine competing mod- els and to identify the model that best depicts the network con- nectivity during the task.

In contrast, other, more commonly used types of neuroimaging analyses such as General Linear Model analyses and functional connectivity analyses (van den Heuvel and Hulshoff Pol, 2010) examine correlations between neural activity and behavioral performance and between different regions of interest, respectively. Therefore, these analyses do not examine the reciprocal influence of brain regions and the directionality of those effects. Alter- natively, Granger Causality analysis (Roebroeck et al., 2005) does estimate the directionality of the effects from one region to an- other. However, Granger Causality analysis assumes that the hemodynamic response is known for each voxel, and when it is not, the directionality of effects can be misestimated. In summary, DCM represents the best tool to examine the neural connectivity of the various specified models and to estimate the size and direction- ality of the effects of regions within the network we have identified.

In the current study, we applied DCM to an existing fMRI dataset to compare the flexible neural adaptation that occurs during the execution of novel tasks (i.e., when cognitive flexibility is necessary) in bilinguals and monolinguals. In particular, we used DCM to compare the relative fits of three different models that specify how the regions discussed previously collaborate to carry out novel tasks. By comparing these models, we will accomplish two goals: (1) ascertain which model best explains the network dynamics that give rise to cognitive flexibility and (2) examine whether the best model's parameters differ between bilinguals and monolinguals. Accomplishing these two goals will allow us to connect the characteristics of network dynamics to differences in executive functioning that occur with the early acquisition and proficient use of two or more languages during early development.

1.3. Competing models of cognitive flexibility

The primary goal of the current study is to further understand the neural basis of the relative advantages in executive function- ing, specifically in cognitive flexibility, demonstrated by bilinguals. An understanding of the characteristics of the neural network responsible for cognitive flexibility is foundational to this goal. Based on the previous discussion regarding the regions involved both in cognitive flexibility and language control in bilinguals, there appear to be at least three different mechanisms that may drive the neural adaptation necessary for cognitive flexibility. Thus, three separate, but comparable, DCM models were specified and estimated using the regions known to be involved in cognitive flexibility as part of the common model architecture. Each model focuses on different proposed mechanisms for driving neural adaptation at the point of a task when cognitive flexibility is needed (during novel execution). These models were compared across all participants and then separately in bilinguals and monolinguals, with the goal of using the best-fitting model to examine potential sources of the difference between bilinguals and monolinguals in cognitive flexibility.

In the first model, labeled the *Prefrontal Modulatory Model*, the influence of the DLPFC on different regions within the network is proposed to drive neural adaptation when cognitive flexibility is needed. The Prefrontal Modulatory Model is based on the research previously discussed demonstrating that DLPFC activity is associated with the formation and maintenance of internal goal and rule representations (e.g., Cole et al., 2010; Miller and Cohen, 2001). Specifically, this model proposes the idea that the DLPFC drives flexibility by maintaining the necessary goal structure and thus influencing activity in the ACC and striatum downstream.

In the second model, labeled the *ACC Modulatory Model,* the influence of the ACC on different regions within the network drives neural adaptation when cognitive flexibility is needed. The ACC Modulatory Model is based on research previously discussed demonstrating that ACC activity is associated with monitoring response conflict during novel, unpracticed, and/or non-automatic tasks (e.g., Abutalebi et al., 2012; Kerns et al., 2004). In particular, in the ACC Modulatory Model, the ACC's role in the adaptation of the neural network during cognitive flexibility would be mon- itoring for potential conflict and responding by influencing the DLPFC and striatum. This would allow for the appropriate adap- tation within the network (i.e., increasing or decreasing activity in the DLPFC and striatum) to flexibly execute the task.

Finally, in the third model, labeled the *Striatum Modulatory Model*, the influence of the striatum on the different regions within the network is proposed to drive neural adaptation when cognitive flexibility is needed. The Striatum Modulatory Model is based on research previously discussed demonstrating that striatal activity is associated with learning and rule application during the execution of novel tasks (e.g., Muhammad et al., 2006; Stocco and Prat, 2014; Stocco et al., 2010). Specifically, in the Striatum Mod- ulatory Model, the striatum drives the neural adaptation of the network to flexibly execute novel instructions by gating the signal appropriately, influencing activity in the ACC and DLPFC, allowing for adaption within the network. In the current study, the fit of these three models was compared using DCM on data collected from when bilinguals and monolinguals performed a RITL paradigm, which requires cognitive flexibility during the execution of novel tasks.

2. Materials and methods

2.1. Participants

Participants were a subset of the original sample described in Stocco and Prat (2014). Specifically, they were 15 early bilingual individuals and 14 monolingual individuals who were recruited from the student population at the University of Washington and were paid for their participation. The bilingual participants were proficient in two or more languages before the age of 7, as mea- sured by a proficiency score greater than or equal to 7 in both speaking and understanding (on a scale from 1 to 10) in a modified version of the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007), a structured questionnaire ex- amining language usage and acquisition. The current study in- cluded only early bilinguals given previous research showing that age of acquisition modulates the performance of bilinguals (e.g., Luk et al., 2011), with early bilinguals demonstrating the largest differences in executive functioning performance compared to monolinguals. Mean age of second-language acquisition was 2.2 (SD 71.39) and mean proficiency score was 8.63 (SD 7.33). The monolingual participants were proficient in only one language as measured by the LEAP-Q and had not been exposed to any other languages before the age of 13. The demographics and linguistic characteristics of the two groups are detailed in Table 1. Two participants (i.e., one mid-bilingual and one late bilingual) from the original study were discarded to fit these criteria. All partici- pants were right-handed and between the ages of 18 and 27 and were without a history of neurological disorders and mental illness.

2.2. Task

The task used in the current study was a RITL paradigm (see Cole et al. (2013)). RITL paradigms differ from traditional cognitive computer tasks in one important way. Traditional cognitive computer paradigms tend to include an initial set of instructions for the entire task, followed by the application of the same task on a series of stimuli. However, in RITL paradigms, participants are given a different set of instructions for a novel set of variables for each trial, resulting in the encoding of new rules and the execution of a different “task” during each trial. The flexible reconfiguration of behaviors resulting from different instructions for each trial allows the RITL task to approximate the quick adaptability to novel tasks needed in “real world” scenarios. In the current experiment, participants were presented with a set of instructions including three arithmetic operations (selected from a set of ten different operations) during each “task”. These instructions were then applied to two input numbers (e.g., x and y), with all tasks containing one binary (e. g. “multiply x by y”), and two unary (e.g., “add 1 to x”) operations (see Stocco and Prat (2014) for more details). The participants were instructed to apply the first operation to x, the second operation to y, and the third operation to the results of the previous operations.

Each “task” was divided into three sequential phases: (1) the Encoding phase which included the presentation of instructions and was participant-paced, (2) the Execution phase which in- cluded the presentation of the variables to be mentally executed (i.e., requiring a mental response) and was participant-paced, and (3) the Response phase which included a possible result that the

Table 1
Composition of the bilingual and monolingual groups.

		Bilinguals	Monolinguals
Group Composition	Size and gender	N¼15 (8 female)	N¼14 (7 female)
	Mean age 7SD	21.475.1 years	22.474.3 years
Linguistic Background	L1	Cantonese (N¼1; Prof¼7.5)	English (N¼14; Prof¼9.86)
		Danish (N¼1; Prof¼8)	
		English (N¼4; Prof¼9.75)	
		Friulian (N¼1; Prof¼10)	
		Japanese (N¼1; Prof¼9)	
		Korean (N¼2; Prof¼9.25)	
		Mandarin (N¼2; Prof ¼9.25)	
		Portuguese (N¼1; Prof¼9.5)	
		Russian (N¼1; Prof¼8.5)	
		Spanish (N¼1; Prof¼10)	
	L2	English (N¼10; Prof¼9.35)	
		Italian (N¼1; Prof¼10)	
		Korean (N¼2; Prof¼8.25)	Hindi (N¼1; Prof¼1.5)
		Mandarin (N¼1; Prof¼7.5)	Spanish (N¼1; Prof¼3)
		Spanish (N¼1; Prof¼7.5)	
	L3	English (N¼1; Prof¼7.5)	Spanish (N¼1; Prof¼5)
		German (N¼1; Prof¼2)	
		Indonesian (N¼1; Prof¼UK)	
		Spanish (N¼1; Prof¼UK)	
	L4	Cantonese (N¼1; Prof¼UK)	N/A
	L5	Japanese (N¼1; Prof¼UK)	N/A

Note: Prof¼the average speaking and understanding proficiency; UK¼unknown.

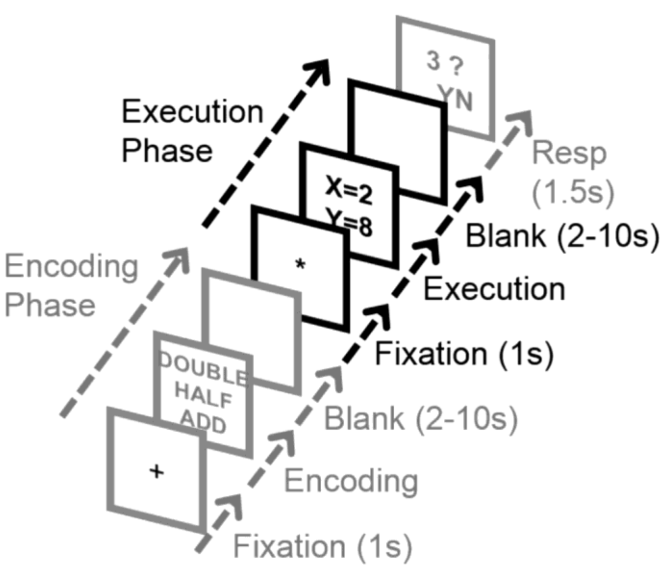

Fig. 1. The time-course of a sample RITL trial used in the current research.

participants had to accept or reject with a button press in 1.5 s (as shown in Fig. 1). The presentation of a novel set of instructions during each trial and the separation between encoding the instructions and executing the instructions on a set of variables during the RITL paradigm allows for the specific examination of how the underlying neural network and the associated behavior flexibly adapt during the execution of novel tasks.

The RITL paradigm is useful not only because it approximates a real-world application of cognitive flexibility, but also because the paradigm shares critical behavioral and neural features with the bilingual language experience, making RITL an ideal paradigm for investigating executive functioning advantages in bilinguals. For instance, behaviorally, the cognitive flexibility needed during the execution of tasks that involve novel instructions or rules approximates the cognitive flexibility needed when bilinguals select and combine linguistic rules based on the appropriate target language. Neurally, the flexible execution of novel tasks in RITL paradigms recruits brain networks that overlap with the pre- viously discussed bilingual language control networks. In fact, language control in the bilingual brain appears to operate ac- cording to the flexible application of and adaptation to rules (Buchweitz and Prat, 2013), and the frequent need for flexibility in language control may train the neural network responsible for cognitive flexibility. This increased flexibility may generalize to other tasks, such as RITL, that require the flexible adaptation of behavior and the associated neural network to novel instructions or rules. Similar to the previous discussion regarding cognitive flexibility in Section 1, the RITL task requires several components of executive functioning such as switching (e.g., to a new rule), updating (e.g., changing the goal structure to a new task), mon- itoring response conflict (e.g., executing or "mentally responding" to novel (low frequency) trials in the midst of practiced (higher frequency) trials), and maintaining the task goal.

2.3. Procedure

The study was undertaken with the understanding and written consent of each participant. Data were collected during the course of three separate sessions run across three separate days, with sessions two and three occurring within 24 h of one another. Session one included the collection of English reading proficiency (The Nelson-Denny Reading Test; Brown et al., 1993), working memory capacity (the Automated Operation Span test; Unsworth et al., 2005), and language history and proficiency (i.e., the LEAP- Q) measures. Participants who met the requirements for a neu- roimaging session were invited back for session two, which in- cluded a practice session of the RITL paradigm where participants practiced two combinations of the basic arithmetic operations totaling 4 blocks of 10 trials each. Session three included an fMRI experiment where participants performed the RITL experiment while in an fMRI scanner. Participants completed 4 blocks of 10 trials each, with all trials containing jittered inter-stimulus inter- vals and with half of the trials (i.e., 20 trials) consisting of encoding previously practiced instructions and executing those practiced