Putting together bilingualism and executive function

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Three important issues bear on understanding the connection between bilingualism and executive function. The first is the absence of a fine-grained task analysis for executive functions and other cognitive processes. The second is the absence of a theory of the cognitive mechanisms underlying the deployment of two or more languages and thus the absence of a solid basis on which to make predictions about what domain-general performances, if any, bilinguals should excel in. The third is the relation between neural and behavioral consequences of bilingualism. These three issues must be taken in account in trying to understand the variability among findings showing benefits of bilingualism for executive function.

Keywords: Executive function, variability in benefits

The study of executive functions can be, and primarily has been, developed independent of its implications for research in bilingualism; similarly, the study of bilingualism is of rich interest independent of its implications for executive function. But by investigating the two fields together, we can learn more both about the types of activities that improve executive function and about the specific mechanisms underlying speaking two or more languages. This discussion focuses on trying to understand the variability of effects of bilinguals on executive functions (Valian, 2015a, 2015b).

Variability in the reports of superior bilingual performance on tasks tapping higher-level cognitive functioning is the rule rather than the exception in all populations that have been studied so far – children, young adults, older adults. Two logical possibilities concerning whether bilingual superiority is "real" are discussed by Valian (2015a, 2015b).

1. One possibility is that there is *no* cognitive benefit of bilingualism (see, e.g., Paap, Johnson, & Sawi, 2015). Experiments that have reported a benefit should

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be understood as artefactual, the result of other factors. For example, bilingual groups might have other confounding positive characteristics in a particular sample (such as high socioeconomic status, e.g., Morton & Harper, 2007, or immigrant status, e.g., Chertkow, Whitehead, Phillips, Wolfson, Atherton, & Bergman, 2010). Or, bilingualism might be associated with some other active property that is difficult to separate from bilingualism (such as biculturalism). Or, bilingualism might itself be the product of superior cognitive functioning (see, e.g., Li and Grant, 2015, for the suggestion that both directions of effects be examined). Or the results might be an artifact of small sample size (Paap, et al, 2015) or of selective reporting of positive effects (de Bruin, Treccani, & Della Sala, 2015).

2. The second possibility is that there *is* a benefit of bilingualism for executive function, but that the benefit competes with other benefits. Bilingualism is but one of many different cognitively challenging activities that might contribute to superior executive function (as noted, e.g., by Craik, Bialystok, & Freedman, 2010). Depending on the composition of each group in any given experiment, the other benefits may be more plentiful in the monolingual than bilingual group (or sufficiently plentiful in both groups), so that benefits of bilingualism are invisible. This is the possibility that I favor: I suggest that there is a benefit, but it competes with other known benefits.

Three considerations lead me to favor the second possibility. *First*, executive functions are multiple (Miyake & Friedman, 2012). Depending on the tasks we use to measure executive functions, one or another component may be primary. We do not have a clear enough theory yet to isolate what components of executive function should be most affected by bilingualism. As Friedman (this volume) and others have noted, tasks are impure: tasks that tap executive function also inevitably tap other cognitive components that are not part of executive function, such as visual perception. Without an executive function theory, a task theory, a bilingualism theory, and a theory of how all three interact predictions will be very difficult.

Second, we already know that a range of experiences is associated – inconsistently – with superior executive function, delay of dementia, or both. In addition to language status (mono- or bilingual), factors include socioeconomic status; immigrant status; extent of exercise; presence of musical training; experience with action video games; education level; time spent in leisure activities; and, possibly, personality variables (Valian, 2015a). No effects, regardless of domain, uniformly improve executive function. There are, no doubt, still other factors yet to be systematically investigated. Since managing two or more languages is a cognitive challenge, it would be very surprising if bilingualism were not among the challenging factors that contribute to superior executive function. Despite some experimental reports of null effects of bilingualism in which no detectable benefits of accompanying musical experience, video game experience, or exercise are evident (von Bastian, Souza, & Gade, 2016), this is an understudied area.

Third, in all cases, whether looking at language status or other variables, the inconsistent effects are generally – not always, but generally – positive when they do occur. No variable seems to trump any other variable. Once an individual has a number of challenging experiences it will be difficult to find a benefit of any one of them individually. In addition, we do not know how benefits combine. It is clear that benefits are not necessarily additive. They may be incrementally additive to a certain point and then flat. They may be insufficient unless there are a certain number operating in combination. We simply have too little information about the characteristics that improve executive functioning to know what to predict.

To make further progress on the role of bilingualism in cognitive processes, we need to address three issues comprehensively and systematically.

Issue 1. A detailed task analysis is necessary in order to interpret reports of difference – or lack of difference – between mono-and bilinguals on tasks that involve executive functions.

Executive functions coordinate, regulate, and integrate lower-level cognitive processes. Working memory and inhibition of prepotent responses are two examples of executive functions, and visual perception is an example of a "lower-level" cognitive process. (See Friedman, this volume, for a detailed discussion of executive functions.) Although different executive functions can be conceptually separated from each other, more than one is generally active. Further, it is difficult to find a task that measures only a single executive function, and it is impossible for a task to measure only executive functions, because more basic cognitive processes are required in every task (Miyake & Friedman, 2012; Valian, 2015a). Every task is "impure", meaning that it tests different aspects of executive function to different degrees, and also involves cognitive processes outside of executive function, such as visual perception.

One result of task impurity is that tasks that superficially look as if they should correlate may not. Consider, for example, the Simon task and the flanker task. In the Simon task a participant sees red or blue rectangles (or other forms) on the left or right of a computer screen. The task is to use a key on the right of a keyboard for one color, regardless of its left-right position on the screen, and a key on the left of a keyboard for the other color, again regardless of its position. For participants, it is natural to press a key on the side corresponding to the side of the visual display. The participant must thus inhibit the tendency to respond isomorphically on the basis of position and instead respond only on the basis of color. Congruent trials are trials where the color, say, red, and the side of the keyboard one presses, say, right, coincide. Incongruent trials occur when the red rectangle is on the left side of the screen but the keypress must be made on the right side of the keyboard. Since two different colors are involved, participants also have to switch from one side of the keyboard to the other. The Simon "effect" is the difference in reaction time between incongruent and congruent trials.

The superficially similar flanker task involves indicating the direction of an arrow. The arrow may be flanked by other arrows pointing in the same direction as the focal arrow or the other direction. Participants press a key corresponding to the direction of the arrow – a right hand key for an arrow pointing right and a left hand key for an arrow pointing left. Congruent trials occur when both the target arrow and its flankers appear in the same direction, incongruent trials occur when the target arrow points in one direction and the flankers point in the opposite direction. The flanker "effect" is the difference in reaction time between incongruent and congruent trials.

Thus, both tasks involve directionality, and both require the participant sometimes to use a finger on one side of the keyboard for one response and a different finger on the other side of the keyboard for another response. Both tasks have congruent and incongruent trials. But the tasks also differ. One involves non-directional rectangles and the other involves directional arrows.

More importantly, the two tasks have different sources of incongruency. In the flanker, incongruency is due to a conflict between the direction of the target arrow in the *focus* of attention and the direction of the arrows in the *periphery* of attention (Guiney & Machado, 2013; Valian 2015a). The flanker requires one to ignore the arrows surrounding the target. In the Simon task, incongruency is due to a lack of alignment between the spatial position of the stimulus and the spatial position of the key to be pressed. At any given time there is a single stimulus and it is always in the participant's focal attention, whether it is congruent or incongruent. The Simon requires inhibition of a prepotent response whenever the stimulus is on the other side of the screen from the keyboard response, while the flanker does not (Poarch & Van Hell, 2012).

Such seemingly minor task differences are sufficient to result in a lack of correlation between the Simon effect and the flanker effect. Average overall reaction time, independent of congruency condition, correlates well: people who are fast overall on the Simon task are fast overall on the flanker task, because fast people are fast. But the cost of incongruency does not correlate. Individuals who show a low cost of incongruency on the Simon do not show a similarly low cost on the flanker (Paap & Greenberg, 2013; Humphrey & Valian, 2012; Poarch & Van Hell, personal communication, 30 Dec 2012). In an even more surprising example, the verbal and numerical versions of the Stroop test do not correlate (Duñabeitia, Hernández, Antón, Macizo, Estévez, Fuentes & Carreiras, 2014). Since the tasks are conceptually extremely similar, it seems likely that cognitive processes outside of executive function are responsible for the differences in responding.

Absent a detailed task analysis, there is a hole of uncertainty accompanying reports of difference – or lack of difference – between any two groups on tests of executive function. Reported differences may be due to the aspects of a task that measure executive function or they may be due to aspects that measure other cognitive processes or they may be due to an interaction. The lack of consistency from one experiment to the next in what tasks are used and what data are reported on makes it especially difficult to know what the underlying benefits might be.

Issue 2. We need a better basis for predicting the cognitive consequences of bilingualism.

In the same way that we do not have a detailed understanding of the tasks used to measure executive functions, we do not have a detailed understanding of the cognitive processes that bilinguals use in speaking and listening. The consequence of our lack of understanding is difficulty in predicting on what tasks bilinguals should show superior performance. And although I speak here of "bilinguals", different types of bilinguals may deploy different mechanisms in speaking and listening.

Life-long balanced bilinguals – exactly the group that has been suggested as most likely to outperform monolinguals on executive function tasks (Luk, De Sa, & Bialystok, 2011) – are very highly practiced. If such bilinguals' skill in switching from language to language is automatic, the cognitive processes involved may have become so modularized and encapsulated that there are no domain general consequences. Predictions that suggest that bilinguals will be better at general task-switching or inhibition than monolinguals are based on the fact that at least some balanced bilinguals switch frequently between their languages and on evidence that the vocabulary and grammar of both of a bilingual's languages are always active (Kroll, Bobb, Misra, & Guo, 2008), a finding reminiscent of results showing that all of the meanings of an ambiguous word are briefly available to speakers (e.g., Onifer & Swinney, 1981). But such findings do not bear directly on the issue of whether executive control has been automatized.

The fact that interpreters, who switch ultra-frequently between languages, show minimal superiority in executive function over other bilinguals (or, in some experiments, monolinguals) suggests that automatic skill may not yield domain-general benefits in executive function, with the possible exception of working memory (e.g., Babcock & Vallesi, in press; Stavrakaki, Megari, Kosmidis, Apostolidou, & Takou, 2012; Yudes, Macizo, & Bajo, 2011). Other reports suggest very selective benefits of being a simultaneous translator (Morales, Padilla, Gómez-Ariza, & Bajo, 2015).

Thus, clear benefits for a range of executive functions may only be observable when executive control is actively involved in multi-language processing – exactly contrary to early suggestions. Bilingual babies – who cannot be said to be inhibiting or updating or switching in the usual sense of those terms – nevertheless appear to show enhanced executive functions, as measured by a task that requires learning a second rule after learning an initial rule (Kovács & Mehler, 2009). This is a suggestive finding, since babies are likely utilizing general regulatory functions in dealing with two sound systems.

Absent a detailed analysis of the cognitive processes that bilinguals (and different types of bilinguals) use when processing language, and the ways that those processes differ from the processes that monolinguals use, there is another hole of uncertainty, this time about the conditions under which bilinguals should be superior to monolinguals.

Issue 3. We do not understand the connection between behavior and the brain.

Juggling two or more languages has demonstrable neural consequences. The question is to what extent those neural differences are relevant to behavior and cognition (Li, Legault, & Litcofsky, 2014; Li & Grant, 2015; Valian, 2015a). Cognitive processes and neural processes are not the same thing. The dissociation between neural differences and behavioral differences holds both in the domain of bilingualism and in the domain of cognitive sex differences. De Vries (2004) has noted that the functional significance of most sex differences in the brain is not known, writing, "We are heavily invested in the idea that sex differences in brain structure *cause* [my emphasis] sex differences in behavior. We rarely consider the possibility that sex differences in brain structure may also *prevent* [my emphasis] sex differences in overt functions and behavior, by compensating for sex differences in physiological conditions, such as gonadal hormone levels that may generate undesirable sex differences if left unchecked." De Vries (2004) suggests that differences in brain-behavior correlations exist because some behaviors need to be carried out equally well by both sexes. Neural-hormonal differences that arise as part of sexual dimorphism need to be counterbalanced by mechanisms that will allow equally good performance by both sexes.

Although de Vries's (2004) compensation hypothesis is directed to sex differences, it applies equally to any two groups. In the case of mono- and bilinguals, both groups need to be able to carry out executive functions. One group may do it with one set of neural pathways and another group may do it with a different set. How each group's behavior is mediated by different neural circuitry is of great interest, but since two groups can accomplish the same task by different neural means, the fact that the brains of bilinguals are different from the brains of monolinguals does not inform us about the *cognitive* processes underlying bilinguals' behavior.

More specifically, there are two problems that Poeppel (2012) has dubbed the *maps problem* and the *mapping problem*. The *maps problem* between brain and behavior is that spatial and temporal localizations in the brain provide correlations with behavior but they do not provide explanations of behavior. In the case of bilingualism, those correlations are inconsistent (Li, Legault, & Litcofsky, 2014; Li & Grant, 2015; Treccani & Mulatti, 2015). Even if it will someday be possible to perfectly localize function and identify processing streams, we still will not have an explanation of the mechanism. We still will only have a correlation.

Poeppel says, "… systematic relations consistently occur between brain areas and some functions that reappear across studies, but we have no *explanation*, no sense of which properties of neuronal circuits that we understand account for the execution of function". He goes on to say, "We [need to] decompose the cognitive tasks under investigation into computational primitives that can be related to local brain structure and function, in a sense instrumentalizing the computational theory of mind." The crucial point is that a *cognitive* explanation is not the same as a *neural* explanation, especially if the behaviors at issue are identical. A cognitive explanation will allow for the possibility that different neural circuits subserve the same cognitive performance. A cognitive explanation will be independent of the neural differences.

That gets us to the *mapping problem* (Poeppel, 2012). We lack linking hypotheses to connect, in this case, bilingual language processing with neural processing. The vocabulary of the two domains is different. The vocabulary of bilingual language processing includes terms like "word retrieval" and "code-switching"; the vocabulary of the brain includes terms like "increased firing" and "network patterns". Those are incommensurate and require a theory that will link them (Poeppel, 2012).

Thus, although studies of the brain contribute to our understanding of bilingualism, they can lead to an illusion of greater understanding than we in fact have. We know that brains can operate differently to produce the same result, just as calculators can use different internal logics to yield the same answers to arithmetic problems. We are interested in something fundamental about mental arithmetic that is independent of the particular logical system governing the operation of the calculator. In bilingualism, we are correspondingly interested in something fundamental about cognition that is independent of the brain.

In sum, I propose that the inconsistencies in findings relating bilingualism to domain general cognitive processes are due to the many-many connections among the variables of interest. Executive functions are multiple, the task components are multiple, types of bilingualism are multiple, the cognitive processes involved in being bilingual are multiple, brain differences are inconsistently and multiply associated with behavioral differences, and the set of cognitively challenging experiences that may improve executive functions is multiple. We still know relatively little about executive function and the tasks that are used to measure its components and we still lack enough understanding of bilingual processing and how it differs among individuals and among different types of bilingualism.

The range of executive functions, the range of tasks measuring executive function, and the range of experiences that are associated with superior executive function raise an important question about mechanism. Is there a single mechanism or several different mechanisms underlying superior executive function? If executive function is manifold, if different tasks measure different aspects of it, and if different experiences give rise to better or worse performance on those tasks, it seems likely that there are several different underlying mechanisms. If that is correct, future research should identify the different mechanisms rather than search for a single mechanism.

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