Identifying the Causal Link: Two Approaches toward Understanding the Relationship
between Bilingualism and Cognitive Control

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Paap, Johnson, and Sawi's (2015) review raises a number of methodological issues with the current literature concerning bilingualism and cognitive advantages in executive functions. While the review has focused on providing counter-evidence to a positive relationship between the two, we think that what should be the single most important message may have gotten lost in the article: more work needs to focus on identifying and describing the causal link between bilingual experience and cognitive control, as opposed to work just reporting correlations between the two.

As in all domains of science, it is critically important to develop good approaches toward understanding the causal links between variables of interest (independent variables or IV) and the observed phenomena (dependent variables or DV). The current debate has focused almost exclusively on the IV-DV relationship in which the IV is 'type of language experience' (bilingualism vs. monolingualism) and DV is 'level of executive function' (high vs. low executive function or EF). While Paap et al. (2015) point out some pitfalls in the study of this IV-DV relationship, they mention only in passing that "superior EF may make it easier to achieve higher levels of L2 proficiency" (p. 11). Li (2015) makes a strong case for an approach of study in which the IV-DV relationship is reversed: treating cognitive control as the IV and bilingualism as the DV. This approach implies that we seriously consider people's initial differences in cognitive control, and understand how individual differences in executive function, working memory, and even general intelligence might provide the learner with a better chance for bilingual success. While the use of cognitive control predictors to distinguish between better versus poorer learners has been widely accepted in other fields of language research, it has only just begun to be adopted in bilingual studies. We suggest that this new direction for looking at

the IV-DV relationship could shed light on the existing debate regarding the relationship between bilingualism, cognitive control, and individual differences. In particular, investigations into the dynamic relationships (reversible IV-DV relations) would enable us to evaluate whether enhanced cognitive abilities are the result of bilingual experience, the cause of bilingual success, or both. A number of recent studies have begun to provide promising results in this direction (see Li, 2015; Li, Legault, & Litcofsky, 2014; Linck et al., 2013, for reviews). There is also new evidence that links individual differences in cognitive capacity and brain networks/neural pathways to the individual's performance or success in second language (e.g., Xiang et al., 2012; Yang, Gates, Molenaar, & Li, 2015; Yang & Li, 2012).

A second, perhaps more important, approach, especially if one assumes the existing IV-DV direction (i.e., bilingualism $\rightarrow$ cognitive control), is the use of longitudinal designs to determine whether there is a causal link between bilingualism and cognitive control. Longitudinal designs are time-consuming and resource-demanding (which is why they are still rare), but they are key to disentangling potential confounds such as those mentioned in the Paap et al. (2015) review. Longitudinal designs allow us to track the same individual, regardless of his or her prior language history or cognitive ability, across a period of time from no bilingual experience to low bilingual proficiency to high bilingual expertise. Simultaneously, cognitive control abilities can be measured at various time points across this period. Several recent studies have taken this approach toward bilingualism and second language acquisition; for example, Ljungberg, Hansson, Andrés, Josefsson and Nilsson (2013) analyzed data from 104 bilinguals and 74 monolinguals who were enrolled in a study of aging and memory. All 178 participants

were tested four times over the course of 20 years, and the bilinguals consistently showed improved cognitive abilities in some areas (e.g., episodic memory recall and letter fluency performance) but not others (e.g., category fluency or visuospatial ability), as compared with monolinguals.

Even without following participants for 20 years, longitudinal designs can provide significant insights into the relationship between bilingualism and cognitive control. A recent study by Sullivan, Janus, Moreno, Astheimer and Bialystok (2014) followed two groups of participants, one studying Spanish and another Introductory Psychology for six months, and found significant group differences in ERP response to linguistic and cognitive control tasks after six months (but not behavioral differences; see discussion below). In two more recent studies, Grant, Fang, and Li (2015) and Yang et al. (2015) used longitudinal designs to track second language lexical development in two contexts: Spanish learners in a classroom and Chinese learners in a lab training session, respectively. By tracking behavioral and functional brain changes associated with increased linguistic experience across time, and by testing learners' cognitive control abilities not only after but even before learning, these studies allowed us to dissociate effects due to bilingual experience or cognitive control, thus providing a principled solution to the so-called 'alignment problem' discussed in Paap et al. (2015).

The alignment between behavioral data and neuroimaging data is a highly debatable issue in cognitive neuroscience in general. There is ample evidence that behavioral data and neural data are complimentary, not synchronous, to each other. Sometimes we observe no behavioral performance differences but see neural differences, other times the reverse. The two methods may be sensitive to different aspects of

cognition, and in many cases, the neuroimaging data may reveal important differences not observable in behavior (see Li & Tokowicz, 2012 for a discussion). For example, in McLaughlin, Osterhout, and Kim's (2004) study, short-term training of American students learning French (e.g., within 14 hours) produced no clear performance improvement but the N400 amplitudes were related to the number of hours of L2 instruction. In another study, Chen, Shu, Liu, Zhou, and Li (2007) showed that native speakers of English and high-proficiency Chinese learners of English showed no behavioral differences in detecting subject-verb agreement violations, but their ERP patterns differed. It is possible that compensatory mechanisms may be at work, such that different individuals can perform the task equally well in behavior, but one individual's brain may be working harder to achieve the same level of behavioral performance (e.g., by utilizing more neural resources/areas/networks; see Li & Grant, 2015 for a recent discussion on bilingual brain networks). This presents a challenge to understanding the intricate relationships among behavior, brain function, and brain structure. In this regard, Li et al. (2014) provided a detailed review of experience-dependent neuroplasticity as a function of second language learning, with respect to both anatomical/structural and functional brain changes. Specifically, gray-matter volume or white-matter integrity in key cognitive control areas (e.g., inferior parietal lobule) may be enhanced by increased linguistic experience with aspects of a new language (e.g., vocabulary learning; Mechelli et al., 2004), and such experience-dependent brain changes may provide the bilingual speaker with more 'cognitive reserve' (see also Grant, Dennis & Li, 2014 for a discussion of cognitive reserve in the aging bilingual brain).

If the Paap et al. (2015) article can serve as an impetus to the understanding of the causal links between bilingualism and cognitive control, it will have achieved its goal.

The two approaches discussed here, we hope, can provide useful pointers to future research.

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