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BRIEF REPORT

Novel evidence in support of the bilingual advantage: Influences of task demands and experience on cognitive control and working memory

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Abstract The bilingual advantage—enhanced cognitive control relative to monolinguals—possibly occurs due to experience engaging general cognitive mechanisms in order to manage two languages. Supporting this hypothesis is evidence that bimodal (signed language–spoken language) bilinguals do not demonstrate such an advantage, presumably because the distinct language modalities reduce conflict and control demands. We hypothesized that the mechanism responsible for the bilingual advantage is the interplay between (a) the magnitude of bilingual management demands and (b) the amount of experience managing those demands. We recruited adult bimodal bilinguals with high bilingual management demands and examined cognitive control and working memory capacity longitudinally. After gaining experience managing high bilingual management demands, participants outperformed themselves from 2 years earlier on cognitive abilities associated with managing the bilingual demands. These results suggest that cognitive control outcomes for bilinguals vary as a function of the mechanisms recruited during bilingual management and the amount of experience managing the bilingual demands.

Keywords Bilingual advantage · Working memory · Cognitive control · Simultaneous interpreting

The *bilingual advantage* refers to enhanced cognitive control in bilinguals relative to monolinguals, and has been found in infants, children, and adults (Bialystok & Craik, 2010). Bialystok and colleagues suggested that the bilingual advantage occurs due to bilinguals' experience switching between languages and the languages' respective grammatical properties. In other words, in order to appropriately switch between languages, bilinguals must (a) control the selection of the target language and (b) resolve conflict between competing alternatives; these ongoing demands within bilinguals increase the amount of practice with engaging processes supported by domain-general mechanisms (Bialystok, 1999; Green, 1998). According to this interpretation, the bilingual advantage should be strongest among bilinguals who speak two languages with a high degree of conflict, and weakest among bilinguals who speak two languages with less conflict. A few studies have investigated the effects of degrees of interlanguage conflict on cognitive enhancement. For example, Emmorey, Luk, Pyers, and Bialystok (2008) found that bimodal (signed language–spoken language) bilinguals did *not* outperform monolinguals on tasks of cognitive control. Emmorey, Luk, et al. explained that the lack of a bilingual advantage in this population was likely due to the two languages' distinct motor and perceptual pathways reducing the needs for both conflict resolution (Emmorey, Borinstein, Thompson, & Gollan, 2008) and target language selection (Pyers & Emmorey, 2008)—that is, low interlanguage conflict. In contrast, research with unimodal (spoken language–spoken language) bilinguals of various language pairs with varying amounts of grammatical overlap—and therefore varying amounts of interlanguage conflict—has revealed uniform bilingual advantages in cognitive abilities for children (Barac & Bialystok, 2012). These results suggest that varying levels of interlanguage conflict does *not necessarily* vary the amount of executive control enhancement.

Other studies have also contributed to the debate surrounding the bilingual advantage: Some researchers have failed to observe a bilingual advantage at all (Morton & Harper, 2007;

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Paap & Greenberg, 2013), and in cases in which differences are observed, the effect may be confounded with various group differences (e.g., Morton & Harper, 2007). Some studies have controlled for such differences—for example, socioeconomic status—and still show a bilingual advantage (Bialystok, 2009).

In a domain as complex as bilingualism, many differences among sample groups are likely to emerge, thus making generalizations to all bilinguals difficult. For example, Paap and Greenberg's (2013) finding of no advantage in executive functions among college student bilinguals may have been due to specific features of their sample. For instance, college students may have relatively low *bilingual management demands* (BMD); they are generally surrounded by one dominant environmental language, and therefore receive continuous target language cues. Thus, they may not need to engage as much executive control to manage the bilingual processes of inhibiting the incorrect target language and selecting among competing alternatives as would a bilingual who frequently switches languages or who frequently functions in a multilingual environment. Although evidence suggests that both languages in bilinguals are activated even in monolingual environments (Kroll, Bobb, Misra, & Guo, 2008), recent investigations have shown that those who frequently switch between their languages have enhanced cognitive control as compared with bilinguals who do not frequently switch between their languages (Calabria, Hernández, Branzi, & Costa, 2011; Festman, Rodriguez-Fornells, & Münte, 2010; Prior & Gollan, 2011; Soveri, Rodriguez-Fornells, & Laine, 2011). These findings suggest that cognitive enhancements among (some) bilinguals may not just be a result of being bilingual, or of the degree of similarity between languages, but result from how much one needs to engage cognitive control in order to "manage" the two languages.

The purpose of this study is to investigate whether heightened BMD—the degree to which one must engage cognitive control in order to appropriately use the two languages—enhances cognitive control and working memory (WM), even among bilinguals with low interlanguage conflict. We hypothesized that the degree to which cognitive control mechanisms would be recruited—and therefore, the degree to which a bilingual advantage would emerge—would depend on two variables: (1) the magnitude of the BMD and (2) the amount of experience managing those demands. More specifically, we hypothesized that heightened BMD and experience managing those BMD are necessary to produce enhanced cognitive functioning.

In order to test our hypothesis, we recruited American Sign Language (ASL)–English simultaneous interpreter students. ASL–English interpreter students are bimodal bilinguals, and thus have low interlanguage conflict, but should have high BMD—they need to switch frequently between languages, coordinate the two languages simultaneously, comprehend the source message in one language while producing the target message in the other language, and use executive control to select the appropriate target language in environments in which both languages are cued (Christoffels & de Groot, 2005; Gerver, 1976; Gile, 1997; Lambert, 1992; Padilla, Bajo, Cañas, & Padilla, 1995; Yudes, Macizo, & Bajo, 2012). We varied experience managing these heightened bilingual demands by recruiting beginning (first-semester) ASL–English interpreter students and comparing these same students to themselves later as advanced (fourth-semester) ASL–English interpreter students. We predicted that the ASL–English interpreter students would outperform themselves 2 years earlier on measures of general cognitive abilities engaged during simultaneous interpreting.

Other studies have shown that professional unimodal simultaneous interpreters outperform noninterpreter unimodal bilinguals in measures of mental flexibility and cognitive control (Yudes, Macizo, & Bajo, 2011), and that professional unimodal interpreters outperform unimodal interpreter students, who in turn outperform noninterpreter unimodal bilinguals in WM processes (Yudes et al., 2012). These studies suggest that experience interpreting increases cognitive abilities, but given the cross-sectional designs, we cannot know whether those who succeed as interpreters already have enhanced cognitive abilities or whether experience interpreting causes enhanced cognitive abilities. Our study therefore investigated interpreter students *longitudinally*, in order to determine whether cognitive abilities—namely, cognitive control and working memory capacity—become enhanced with interpreter training.

With respect to cognitive control, we predicted that measures of task switching and mental flexibility—two cognitive abilities often associated with the bilingual advantage—would be enhanced among advanced interpreter students relative to themselves as beginning interpreter students, because simultaneous interpreting demands rapid and flexible switching between sets of grammatical and cultural rules. Simultaneous interpreting also demands maintaining a portion of the source message in memory while transforming another portion of the message into the target language. Therefore, with respect to WM, we predicted enhancement among advanced interpreter students in tasks that required the "coordination and transformation" of information (Oberauer, 2004). In contrast, we predicted that WM, as measured by tasks that require "processing and storage" (e.g., complex span tasks; Unsworth, Heitz, Schrock, & Engle, 2005), would not differentiate advanced and beginning interpreter students. Simultaneous interpreting does not demand the maintenance of information while processing an unrelated task; rather, interpreters are trained to find relationships among pieces of information in order to determine the gestalt meaning of the communication. Finally, although these data were not directly related to our hypothesis, measures of psychomotor speed, perceptual speed, and general fluid intelligence were also administered, in order to gauge other potential differences across groups.

Method

Participants

The participants were 21 ASL–English simultaneous interpreting students.[1] The interpreter students were recruited in their first semester and were retested in their fourth (final) semester. All participants were recruited from two institutions with similar curricula.[2] Demographic information is presented in Table 1.

Procedure and materials

We included measures of seven cognitive constructs.[3] Two of these constructs were representative of those common to the bilingual advantage literature: *task switching* and *mental flexibility*. We measured two types of cognitive processing speed—*perceptual speed* and *psychomotor speed*—and also included two tests of *nonverbal intelligence/reasoning ability*. Finally, we measured WM in two ways: We measured one's ability to coordinate and transform maintained information (*coordination* and *transformation*), and also one's ability to maintain information in the face of interference (*storage* and *processing*). (See Table 2.)

Results

Our predicted pattern emerged: The advanced interpreter students outperformed themselves as beginning interpreter students on multiple measures, including task switching ($p < .08$, $d = 0.99$) and mental flexibility ($p < .05$, $d = 0.67$), psychomotor speed ($p < .01$. $d = 1.91$), nonverbal intelligence/reasoning ability (Raven's, $p < .08$; Cattell's, n.s.; ds = 0.65 and 0.63, respectively), and WM coordination and transformation (ps < .05, ds = 0.76 and 0.85, respectively), but not WM storage and processing (n.s., ds = 0.18 and 0.05, respectively); see Table 3.

Table 1 Demographic information

Sample Size	
Institution I	13
Institution II	8
Age	
M (*SD*)	26.24 (5.08)
Median (range)	24 (21–40)
CODAs	3
Female	18
Semesters of College Education	
M (*SD*)	8.81 (3.78)
Median (range)	8 (2–17)
Semesters of ASL	
M (*SD*)	4.90 (2.28)
Median (range)	5 (1–12)

CODAs, Children of Deaf Adults (participants exposed to ASL since birth)

Additional analyses and discussion

Overall, the results are consistent with the notion that the magnitude of bilingual management demands and the amount of experience managing those demands predict enhancement in cognitive control and WM. It is important to consider, however, potential confounding variables—that is, other variables varying across the groups that might also contribute to the observed effects.

First, being raised as a bilingual could be driving the effects: Three of the 21 interpreter students had learned ASL since birth. We therefore excluded these individuals and repeated our analyses. The results were consistent with the original findings, suggesting that these individuals were not driving any of the observed effects. Two p values changed slightly, but this was to be expected, given the reduction in degrees of freedom; all of the effect sizes remained relatively stable (task switching, 0.96; mental flexibility, 0.82; perceptual speed, 0.48; psychomotor speed, 1.85; intelligence/reasoning ability, 0.63/0.61; coordination and transformation, 0.96 and 0.74; storage and processing, 0.07 and 0.02).

Second, it is possible that the program selection and progression criteria could differ between the interpreter programs and that these criteria could play a role in the effects observed here. Institution was entered as a covariate for all of the analyses, and we found no significant differences on any of the measures between participants in the two institutions (all ps > .05).

[1] To the best of our knowledge, none of the participants were fluent in a third language.

We also collected data from ASL students; however, due to high attrition we were unable to collect longitudinal data from this sample, and so collected cross-sectional data from beginning and advanced ASL students. The cross-sectional design made comparison to the interpreter students difficult. Therefore, the results from the ASL sample are included in supplemental materials.

[2] One school used a trimester schedule (Fall 2010–Spring 2012, minus the summer), whereas the other employed semesters (Fall 2010–Fall 2012, including the summer). We adjusted by recruiting participants on the basis of program advancement (i.e., recruiting students who had completed approximately 20 % of the program [beginning students] and who had completed approximately 80 % of the program [advanced students]). We will use the more common term "semester" to refer to the division of terms for both schools.

[3] The tasks that we chose exhibit strong test–retest reliability and weak practice effects; taken in addition to our long test–retest interval, this suggests that the observed effect sizes were not inflated by test-specific practice (Salthouse & Tucker-Drob, 2008; Unsworth et al., 2005).

Table 2 Measurement information

Construct	Tasks	Reference	Participants Are Asked To
Task-switching	- Connections B: Letters-Numbers - Connections B: Numbers-Letters	Salthouse et al. (2000)	. . . rapidly alternate between connecting numbers and letters to one another in a limited time frame (20 s per page).
Mental flexibility	- Wisconsin Card Sorting Test	Berg (1948)	. . . learn a rule for sorting cards based on feedback and adapt to new sorting rules when the feedback becomes inconsistent with the previous rule.
Perceptual speed	- Pattern Comparison - Letters Comparison	Salthouse & Babcock (1991)	. . . determine whether abstract figures or strings of letters on either side of a line are the same or different as quickly as possible.
Psychomotor speed	- Connections A: Letters - Connections A: Numbers	Salthouse et al. (2000)	. . . draw lines in a sequence (numerical or alphabetical) as quickly as possible.
Nonverbal intelligence	- Raven's Advanced Progressive Matrices - Cattell's Culture Free Test	Raven (1962); Cattell, Cattell, & Institute for Personality and Ability Testing (1960)	. . . recognize patterns and solve problems on the basis of novel nonverbal patterns.
Working memory: Coordination & transformation	- Backward digit span - Letter–number sequencing	(no specific referenced associated with backward digit span); adapted from Wechsler (1997)	. . . mentally transform the presented stimuli into a different order for recall.
Working memory: Storage & processing	- Automated Reading Span - Automated Operation Span	Unsworth et al. (2005)	. . . recall memoranda in sequence while performing a secondary unrelated processing task (deciding whether sentences make sense or not, or solving math problems).

Table 3 Within-group contrasts: interpreter students

Measures	Beginning Interpreter Students			Advanced Interpreter Students			Cohen's *d*
	M	*SD*	95 % CI	*M*	*SD*	95 % CI	
Cognitive Control, Speed, and Reasoning							
Task Switching							
Connections B†	18.64	3.96	16.57–20.69	21.31	5.14	19.23–23.36	0.99
Mental Flexibility							
Wisconsin Card Sorting Test*	76.93	10.72	72.61–81.37	83.26	4.55	78.93–87.69	0.67
Perceptual Speed							
Pattern/letter comparisons	.63	.08	.59–.68	.67	.10	.63–.71	0.46
Psychomotor Speed							
Connections A**	33.64	5.63	30.73–36.51	39.55	5.60	36.63–42.42	1.91
Intelligence/Reasoning Ability							
Raven's matrices†	.50	.16	.43–.57	.59	.17	.52–.66	0.65
Cattell's Culture Fair Test	.53	.11	.49–.58	.58	.13	.54–.63	0.63
WM Capacity							
Coordination & Transformation							
Letter–number sequencing*	.86	.06	.83–.89	.91	.06	.89–.94	0.76
Backward digit span*	.88	.06	.84–.91	.93	.06	.89–.97	0.85
Storage & Processing							
Automated reading span	.68	.19	.61–.76	.72	.17	.64–.80	0.18
Automated operation span	.67	.26	.56–.78	.68	.27	.57–.79	0.05

Measures of speed and task switching are scored as either numbers or proportions of correct responses within a time limit. 95 % CI, 95 % confidence interval of the mean. $^{\dagger}p < .08$, $^{*}p < .05$, $^{**}p < .01$

Relatedly, the effects could be driven by self-selection or progression criteria at the individual level. In other words, interpreter students with higher cognitive abilities might be more likely to enter and to progress through an interpreter program, and therefore our findings could be the result of initial cognitive abilities and not of the interpreter training. We contacted teachers and the nine interpreter students who participated in the study as beginning students but did not participate as advanced students. Of the nine who left the study, three left the study but progressed through the program with their peers, and one temporarily left the program for personal reasons and came back to finish. We compared the remaining five (one of whom had been learning ASL since birth) to the other beginning interpreters who progressed in both the interpreter program and the present study. Although firm conclusions should not be drawn from this limited sample, pairwise comparisons revealed that this group of five did not differ in any of the cognitive ability measures from the beginning interpreters who had continued in the study, tentatively suggesting that initial cognitive control, WM capacity, and general intelligence did not differentiate those who complete the program from those who did not.

Finally, to further test whether the increase in cognitive abilities for the interpreter students could be explained by preexisting cognitive abilities, we conducted regression analyses with initial (beginning student) scores as the predictor variable and the gain scores (advanced student scores minus beginning student scores) as the outcome variable. The initial score was predictive of the gain score in three measures: the Wisconsin Card Sorting Test, backward digit span task, and letter–number sequencing task. However, in these cases, initial score *negatively* predicted gain score. Inspecting scatterplots revealed a ceiling effect. Those initially near the highest possible score on the tasks had lower gain scores, since there was not room for improvement: The farther from ceiling the initial score, the more that these participants improved from the beginning to the end of the program (Wisconsin Card Sorting Test, $\beta = -.906$; letter–number sequencing, $\beta = -.585$; backward digit span, $\beta = -.587$). Taken together, the evidence does not support the idea that the participants in this study experienced cognitive enhancements due to institutional or participant characteristics (i.e., learning ASL in childhood, higher initial cognitive abilities.)

Discussion

Given that previous findings with bimodal bilinguals (with far more bilingual experience than our sample had) have *not* demonstrated enhanced cognitive functions (Emmorey, Luk, et al., 2008), and that participants in our sample who had learned ASL since birth did not seem to be driving the effects, the results suggest that experience with ASL alone does not produce cognitive enhancements. Instead, the results support our hypothesis that the mechanism responsible for cognitive enhancements among bilinguals is the interplay between the magnitude of BMD and the amount of experience managing those demands. We found that among bilinguals with high BMD, experience enhanced cognitive control and WM: The advanced interpreter students demonstrated a bilingual advantage. This finding is consistent with previous results in similar populations, namely Yudes et al.'s (2011, 2012) findings that simultaneous (unimodal) interpreters—bilinguals who have higher target language selection demands and interlanguage coordination demands—outperformed bilinguals with less interpreter experience and bilinguals with lower BMD. Our study was able to demonstrate *longitudinally* that simultaneous interpreters' cognitive control and WM improve with experience.

We observed cognitive enhancements—sometimes of a magnitude near or over a standard deviation—among bilinguals with high BMD and experience managing those demands, relative to themselves before they had accumulated experience managing these demands. Our results also suggest that the specific mechanisms engaged while managing bilingual demands depend on the specific performance demands of the bilingual processing task. For example, ASL–English interpreters have high hand–eye coordination demands—demands that unimodal spoken-language bilinguals presumably would not have. We observed enhancements specific to this demand—that is, enhanced psychomotor speed. We also observed another BMD-specific enhancement—that is, one specific to the cognitive demands of simultaneous interpreting—in the dissociation between WM task types: We only observed enhancements to WM when the task engaged processes assumed to be active during simultaneous interpreting.

The bilingual advantage has generated many years of interesting research, but the source has remained controversial. We assumed that the bilingual advantage does not occur from maintaining two languages within an individual, per se, but occurs from experience managing bilingual demands. When BMD are high, such as when an individual rapidly switches between the languages and must coordinate the comprehension and production of the two languages simultaneously, the individual heavily recruits cognitive control mechanisms in order to manage this language task, leading to cognitive control and WM enhancements.

Our results suggest a possible explanation of why researchers working with different bilingual populations find discrepant results: Bilingual populations differ in their experiences with, magnitude of, and type of BMD (e.g., college students habituated to the majority language differ from those who frequently switch languages), and therefore are likely to differ in their executive control enhancement. Our results also provide a potential framework for understanding the relationship between performance demands and cognitive enhancements, not only among bilingual populations, but also in general as individuals acquire and perform complex skills with varying demands.

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