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Running-head: Novel word learning and cognition in bilinguals

Novel-word learning, executive control and working memory: A bilingual advantage*

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Abstract

Studies of the effects of bilingualism on cognition have given results that do not consistently replicate, reflecting at least in part wide differences in criteria for bilingualism and heterogeneity of language combinations within studied samples. We examined the bilingual advantage in attention, working memory and novel-word learning in early sequential Hindi-English bilinguals. We sought to clarify the aspects of cognition that benefit from bilingualism by using multiple measures and a sample sufficiently well-defined to permit independent replication. Bilinguals outperformed monolinguals on response inhibition, novel-word learning and almost all working memory tasks. In contrast, both groups performed comparably on selective attention. Analyses of individual differences showed that bilingual novel-word learning was related to their verbal working memory and ability to inhibit an ongoing action whereas this was not the case for monolinguals. Results indicate a specific bilingual advantage that is confined to some but not all aspects of cognition.

Recently there has been growing public and academic interest in the effects of bilingualism on cognitive function, with studies suggesting a bilingual advantage relative to monolinguals in executive processing tasks assessing the control over attention to competing cues (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik & Ryan, 2006; Costa, Hernández & Sebastián-Gallés, 2008). Also experience with two or more languages facilitates novel-word learning (e.g., Kaushanskaya & Marian, 2009a, b; Poepsel, & Weiss, 2016; Singh, Fu, Tay, & Golinkoff, 2017) and other aspects of linguistic processing (e.g., metalinguistic awareness; c.f., Reder, Marec-Breton, Gombert, & Demont, 2013). However, despite this there still remains little consensus regarding the impact of bilingualism on cognition (see Gathercole, Thomas, Kennedy, Prys, Young, Viñas Guasch, Roberts, Hughes, & Jones, 2014; Duñabeitia, Hernández, Antón, Macizo, Estévez, Fuentes, & Carreiras, 2014; Hilchey & Klein, 2011). One factor that leads to problems of replication is wide variation in the criteria used to define bilingualism and frequent heterogeneity of language combinations within bilingual samples (c.f., Hua & David, 2008; Miękisz, Haman, Łuniewska, Kuś, O'Toole, & Katsos, 2017). The current study seeks to reduce problems of replicability by using a well-defined group of Hindi-English bilinguals to examine how novel-word learning differs between bilinguals and monolinguals and to examine the extent to which differences in executive processes and other aspects of working memory can account for performance.

Executive control and novel-word learning in bilinguals

Executive control refers to a set of top-down attentional processes that are fundamental to task maintenance and execution (see Miyake & Friedman, 2012). Bilingual adults are reportedly more efficient than their monolingual peers in the deployment of attentional resources and are significantly less affected by irrelevant information (e.g., Hernández, Costa, & Humphreys, 2012). To account for this advantage it has been suggested that the need for bilinguals to focus processing on one language and avoid interference from the other language leads them to develop more efficient processes of executive control (see Green & Abutalebi, 2013). Similarly, recent evidence suggests that the bilingual advantage in novel-word learning may be facilitated by enhanced executive control (see Bartolotti & Marian 2012; Bartolotti, Marian, Schroeder, & Shook, 2011; Kaushanskaya & Marian, 2009a, b), possibly reflecting the need to suppress erroneous responses (c.f., Hammer, Mohammadi, Schmicker, Saliger, & Münte, 2011; Warmington & Hitch, 2014; Warmington, Hitch, & Gathercole, 2013). More generally, executive control abilities have been shown to be a concurrent and longitudinal predictor of vocabulary development in monolinguals, and children and adolescents with specific language impairment show significant deficits in performing executive tasks (see Gathercole, 2006; Rose, Feldman, & Jankowski, 2009).

However, research on cognition in bilinguals has raised a number of concerns. One is the possibility of a publication bias in favour of positive results (see De Bruin, Treccani, & Della Sala, 2015; but, see Bialystok, Kroll, Green, MacWhinney, & Craik, 2015). Another issue is undue reliance on a limited set of measures of executive abilities focused on response conflict (i.e., Simon and Flanker tasks; see Paap & Greenberg, 2013; Paap, Johnson, & Sawi, 2015). The Simon (Lu & Proctor, 1995) and Flanker tasks (Eriksen & Eriksen, 1974) require the resolution of conflict in identifying a target stimulus. In the Simon task the location of the response key is randomly either congruent or incongruent with the location of the target. In the Flaker task the target stimulus is surrounded by non-target stimuli that are either congruent or incongruent to the directional response of the target. Reaction times are faster on congruent trials than on incongruent trials and the size of this congruency effect is taken to reflect the efficiency with which an individual is able to resolve conflict by inhibiting irrelevant information (i.e., Flanker) or a motor reaction (i.e., Simon). Bilingual children and adults have been shown to produce faster reaction times and smaller congruency effects than their monolingual counterparts on both tasks (*Flanker*: Costa et al., 2008; Luk, De Sa, & Bialystok, 2011; *Simon*: Bialystok, 2006; Bialystok et al., 2004; Martin-Rhee & Bialystok, 2008; see Bialystok, 2017 for a review). Crucially, bilinguals demonstrate no time/accuracy trade-off (i.e., their accuracy is comparable to monolinguals) in their faster reaction times highlighting that they are more efficient than monolinguals in performing these tasks (c.f., Kapa & Colombo, 2013). However, not all studies have yielded consistent findings. For example, although Bialystok, Martin, and Viswanathan (2005) found a bilingual advantage on the Simon task in children, middle aged (30-59 years) and older adults (60-80 years), this effect was absent in young adults (20-30 years). Furthermore, Gathercole et al. (2014) found no evidence of a bilingual advantage in children, adolescents (13-16 years) and adults (18-90 years) (see also Paap & Greenberg, 2013 for the Flanker task). In a recent review Hilchey and Klein (2011) found that although bilinguals tended to perform faster than monolinguals, the congruency effect was of similar magnitude. This led them to conclude that bilinguals "enjoy a general processing advantage that can be detected early developmentally and that persists throughout life… [but] places the locus of control not on inhibitory processes per se, but on a central executive system that has some capacity to regulate processing across a wide variety of task demands" (p., 654). The central executive system is a broad construct, comprising a set of correlated but broadly separable processes involving attention, cognitive flexibility and memory updating (see Friedman, Miyake, Young, DeFries, Corley, & Hewitt, 2008; Friedman, & Miyake, 2004; Miyake & Friedman, 2012). Given that the Simon and Flanker tasks measure only limited aspects of executive function (selective attention and conflict monitoring), use of a broader range of tasks to assess the potential cognitive advantages associated with bilingualism may be prudent.

Role of working memory in executive control and word learning

At this point it is useful to consider executive control and novel-word learning in the context of working memory, the limited capacity system responsible for retaining and manipulating information in cognitive tasks. According to the influential model of Baddeley and Hitch (1974), the working memory system consists of a central executive attentional controller interacting with short-term buffer stores for verbal and for visuo-spatial information. Of particular relevance in the present context, the verbal short-term store has been associated with the ability to acquire new (novel) word forms. Thus, neuropsychological patients with a selective impairment in verbal short-term memory show deficits in novel-word learning (e.g., Bormann, Seyboth, Umarova, & Weiller, 2015). Furthermore, verbal short-term memory is a significant predictor of children's vocabulary (e.g., Gathercole, Willis, Emslie, & Baddeley, 1992), as well as their ability to learn novel-words (e.g., Gathercole, Hitch, Service, & Martin, 1997). The verbal short-term store has been conceptualised as a system whose function is to hold new phonological sequences while more stable lexical representations are created in long-term memory (c.f., Baddeley et al., 1998).

In contrast, much less is known about working memory in relation to bilingualism. In a seminal study Papagno and Vallar (1995) compared adult Italian polyglots and controls on verbal paired associate learning (PAL). The polyglots learned word-nonword (Italian-Russian) pairs more efficiently, but performed comparably in learning word-word (Italian-Italian) pairs. They also performed significantly better on measures of verbal short-term memory while performing comparably on tests of visuo-spatial short-term memory (see also Van Hell & Mahn, 1997 for a similar results in the case of Dutch multilinguals). This evidence suggests that the novel-word learning advantage in bilinguals arises as a consequence of enhanced verbal short-term storage capacity. However, in a recent study Kaushanskaya (2012) found that bilinguals outperformed monolinguals in novel-word learning even when their verbal short-term memory ability was matched challenging the view that the novel-word learning advantage was attributed to enhanced verbal short-term memory. Instead, Kaushanskaya argued that the advantage was due to the impact of the bilingual experience on learning (see also Bartolotti et al., 2011; Kaushanskaya & Marian, 2009a, b).

Other findings have been contradictory too. In a group of bilingual children aged between 5 and 7 years Morales, Calvo, and Bialystok (2013) found a bilingual advantage in a task involving visuo-spatial working memory. Similarly, Blom, Küntay, Messer, Verhagen and Leseman (2014) found that Turkish-Dutch children aged 5-6 years outperformed monolingual children on tests involving verbal and visuospatial working memory. In contrast, Engel de Abreu (2011) reported that 6-year-old bilingual children performed comparably to monolinguals on standardised tasks taken from the Luxembourgish adapted versions of the *Automated Working Memory Assessment*

(AWMA: Alloway, 2007) assessing various aspects of verbal working memory (see also Engel de Abreu, Cruz-Santos, Tourinho, Martin, & Bialystok, 2012; Namazi & Thordardottir, 2010). In one of the few studies conducted with adults Ratiu and Azuma (2015) examined verbal and visuo-spatial working memory in Spanish-English bilinguals who had reported speaking both languages before the age of 4. Ratiu and Azuma found that lifelong bilingualism did not facilitate working memory capacity.

In light of this evidence, it remains unclear as to the cognitive mechanisms underpinning the bilingual advantage in novel-word learning. Another limitation of the current evidence is that previous studies have considered the role of attention and working memory in bilingual novel-word learning separately (e.g., Bartolotti et al. 2011; Papagno & Vallar, 1995). We are not aware of studies that have examined the roles of attentional control and working memory mechanisms simultaneously in learning novel-words in bilinguals. In the present study, we compared monolinguals and bilinguals on novel-word learning, executive control and short-term storage and assessed the extent to which these aspects of cognition contribute to the bilingual advantage in novel-word learning.

Overview of present study

Cummins (1976) proposed that a certain level of competence in both languages was required for bilingualism to yield cognitive benefits. Consistent with this, Bialystok and colleagues (e.g., Barac & Bialystok, 2012; Luk et al., 2011) have demonstrated that the cognitive benefits of bilingualism are associated with early onset and significant bilingual experience. Thus, counter to most previous studies we recruited a single population of bilinguals (i.e., Hindi-English) who acquired both languages early on in life. They had started to speak two languages before the age of 7, having achieved fairly equal proficiency in both (often referred to as *early sequential bilinguals*) with lifelong experience of using both languages. The bilinguals were predominantly international university students who lived in India for most of their lives and only recently moved from India to study in the United Kingdom (UK). A group of monolingual English-speaking university students served as controls. Hindi and English do not share scripts, have any commonality in phonology and do not contain cognates (c.f., Mishra & Singh, 2014).

Departing from previous studies that have utilised a single task to assess executive processes (c.f., Antón, et al., 2014; Bialystok, Craik, Grady, Chau, Ishii, Gunji, & Pantev, 2005; Bialystok & Viswanathan, 2009; Duñabeitia et al., 2014; Kirk, Fiala, Scott-Brown, & Kempe, 2014; Prior & Gollan, 2011) we were keen to employ multiple tasks measuring various aspects of attention and working memory to help identify more precisely which aspects of cognition are privileged in bilingualism. Previous studies have differentiated two processes related to attention – one that facilitates suppression of irrelevant information and the other that aids inhibiting prepotent response tendencies (e.g., Bunge, Dudukovic, Thomason, Vaidya & Gabrieli, 2002). We use the terms *selective attention* (i.e., the ability to respond to the appropriate stimulus, while successfully ignoring distracters) and *response inhibition* (i.e., the ability to stop an ongoing response) to denote these two attentional control processes (e.g., Booth et al., 2003) using the Flanker task (Eriksen & Eriksen, 1974) to assess selective attention and the Stop Signal Reaction Time (SSRT) task (Logan, 1994) to assess response inhibition. The Flanker task requires participants to selectively attend to a target (usually by responding to a relevant feature) while ignoring distracters that are either congruent or incongruent to the target. The SSRT task is one in which an infrequently presented stop signal indicates that an ongoing action should be aborted. By varying the delay before presentation of the stop signal the paradigm can be used to measure the time taken to inhibit a simple reaction time response (see Band, van der Molen & Logan, 2003; Logan & Cowan, 1984). Thus, if the stop process finishes before the go process the response is inhibited, but if the go process finishes first the response escapes inhibition and is executed. By applying a horse-race model the SSRT can be calculated as the time required for inhibiting the go response.

To assess the various components of working memory we administered subtests from the AWMA (Alloway, 2007), a standardised measure that taps central executive function in the verbal and visuo-spatial domains, as well as verbal and visuo-spatial short-term memory. There were eight subtests in all, two of each of the four types. They have been standardised with children aged 4-18 years and adults aged 19-23 years, with the adult norms based on students with English as their first language attending UK universities, representing top, average, and low ranking higher education institutions (see Alloway, 2007).

To assess novel-word learning we adopted a modified version of Papagno and Vallar's (1995) word-nonword PAL task. Participants were administered a visual-verbal PAL task which involves learning arbitrary cross-modal associations between a stimulus and response (c.f., Warmington & Hulme, 2012), a process that has been aligned with attentional control (c.f., Abrahamse, Braem, Notebaert, & Verguts, 2016; Blaisdell, Sawa, Leising, & Waldmann, 2006). "Whereas learning is concerned with acquiring new (or updating old) knowledge and skills, cognitive control enables us to counter negative effects of such learning (i.e., when it opposes current goals)." (Abrahamse et al., 2016, p. 693). The design we adopted was in principle very simple; specifically, participants learned Spanish words for a set of novel objects. The Spanish words were selected so that they were dissimilar to words in either Hindi or English in order to focus on learning unfamiliar phonological word forms, as when learning an unusual name for someone you just met (c.f., Papagno and Vallar, 1995). We selected 8 pairs, which is typical of visual-verbal PAL studies (see Mayringer & Wimmer, 2000; Messbauer, & De Jong, 2003; Papagno & Vallar, 1995; Warmington & Hitch, 2014). Unlike previous studies which focused on immediate learning (e.g., Kaushanskaya & Marian, 2009a; Papagno & Vallar, 1995) we were additionally interested in assessing language group differences regarding the integrity of the newly learned items over the long-term. Thus, participants' learning was assessed both immediately and one day later.

Finally, participants were administered a set of measures to assess their general cognitive ability. Fluid intelligence and verbal ability were assessed using the Matrix Reasoning and Vocabulary subtests taken from the *Wechsler Abbreviated Scale of Intelligence* (WASI: Wechsler, 1999) and a tapping task was used to assess motor processing speed.

In summary, we investigated whether bilingual adults show an advantage relative to monolingual peers on a constellation of tasks involving (1) attention and working memory (Experiment 1) and (2) novel-word learning (Experiment 2).

Consistent with research that bilingualism modulates attentional control (see Adesope, Lavin, Thompson, & Ungerleider, 2010) we predicted a bilingual advantage in selective attention (i.e., Flanker task) and response inhibition (i.e., SSRT task). We expected bilingual advantages to emerge on (1) the time required for inhibiting a response (i.e., SSRT task), and (2) congruency effects (i.e., time taken to resolve conflict by inhibiting irrelevant information) and overall response time on the Flanker task; however, we did not expect group differences to emerge on Flanker task accuracy (c.f., Kapa & Colombo, 2013).

Given that working memory is implicated in both language processing (c.f., Gathercole et al., 1997) and executive control (Engle, 2002), there are good grounds to speculate that working memory would be enhanced in bilinguals. Bilinguals' ability to focus processing on one language while avoiding interference from the other language is heavily dependent on working memory (see Thorn & Gathercole, 1999), and lifelong use of working memory resources may lead to enhanced working memory capacity. Thus, we predicted a working memory advantage in bilinguals.

As bilingualism is associated with better attentional control (see Bialystok, 2017) and metalinguistic awareness (Bialystok, Majumder, & Martin, 2003) it has been postulated that these cognitive-linguistic advantages may have additive effects on novel-word learning in bilinguals (see Cenoz, 2003). In light of this, as well as the growing body of evidence (c.f., e.g., Kaushanskaya & Marian, 2009a, b; Poepsel, & Weiss, 2016; Singh, et al., 2017), we predicted a bilingual advantage in novel-word learning. Moreover, given the (1) documented relationship between executive control and working memory (c.f., Engle, 2002); (2) that working memory is implicated in vocabulary development and novel-word learning (e.g., Gathercole et al., 1997); (3) that optimal learning is contingent on a set of sophisticated system that implicitly facilitates the simultaneous monitoring of feedback from the environment, updating a task-appropriate representation and behavioural control

- skills that correspond to working memory and attention (c.f., Duijvenvoorde et al., 2013); and (4) that learning and attentional control are considered as complementary functions (c.f., Abrahamse, et al., 2016), we anticipated that verbal working memory and attention would be concurrent predictors of novel-word learning. Further, we predicted that these relationships would differ between language groups (i.e., attention would be a unique significant predictor in bilinguals, but not monolinguals, due to their enhanced attentional control).

Experiment 1

This experiment examined the bilingual advantage in executive control - working memory, selective attention, response inhibition. Given recent failures to replicate the bilingual advantage in cognition (e.g., Paap et al., 2015), we sought to first establish whether a bilingual advantage exists in a well-defined group of Hindi-English bilinguals. We predicted medium to large magnitude effect sizes (i.e., bilingual advantage) across all measures. We conducted a priori power analyses using the software package, G*Power 3 (Faul & Erdfelder 1992), to determine the appropriate sample size for detecting language group differences in working memory and attention. Given a minimum statistical power (i.e., $1 - \beta$ probability) of .80 with α .05 (Fritz & MacKinnon, 2007), to detect medium to large effects in working memory (Cohen's $d = .45$; Morales et al., 2013) and attention (Cohen's $d = .76$; Engel de Abreu et al., 2012) a *total sample size* of 42 and 44 participants, respectively is required. Experiment 1 has a total of 46 participants and as such there was adequate power to detect the predicted effects.

Method

Participants

Twenty three monolingual adult speakers of English (mean age 23 years, 4 months; 15 females and 8 males) and 23 bilingual adult speakers of Hindi and English (mean age 23 years, 7 months; 14 females and 9 males) with no known hearing problems participated. Both groups did not differ significantly in age, $t(44) = .55$, $p = .87$. All were university students studying in the UK and reported having no knowledge of Spanish. All participants recruited were included in all analyses reported.

Bilinguals completed a language background questionnaire adapted from Bialystok et al. (2004) in which they rated their proficiency in both languages as well as their usage of each language at home, work (or school), and with friends (see Table 1). They reported using English significantly more than Hindi on average, $t(22) = 7.21$, $p < .001$, $d = 2.51$; but rated their proficiency in Hindi and English as comparable, $t(22) = 1.32$, $p = .20$, $d = .42$. In addition, following Flege, Mackay, and Piske (2002) we estimated the degree of bilingualism by dividing reported English proficiency by reported Hindi proficiency (i.e., L2/L1 ratio). The mean ratio was .98 (see Table 1). This did not differ significantly from a value that might be taken to indicate perfect bilingual balance (i.e., a ratio of 1.0), $t(22) = .41$, $p = .69$, $d = .03$. Reported age of initial exposure to English was 3 years, 5 months; with first exposure to English occurring in the home, approximately 11 months earlier than their exposure to English in school, $t(19) = 3.76$, $p = .001$, $d = 1.02$ (see Table 1). All bilinguals reported that they learned English through formal education and by speaking English with others.

< Insert Table 1 about here>

Design and materials

Fluid intelligence and verbal ability

In WASI Matrix Reasoning participants viewed a series of incomplete matrixes and completed each one by selecting the correct response option. In WASI Vocabulary participants provided spoken English definitions for English words presented visually and orally.

Motor processing speed

A motor tapping task which required participants to tap a key as many times as possible in 5000ms was administered. The start of a trial was signalled by a tone followed immediately by a picture displayed for approximately 5000ms and the end of the trial was signalled by a tone and a different visual stimulus. There were three conditions: (1) using the index finger of the preferred hand participants tapped a key on the keyboard as many times as possible (2) using the index finger of the preferred hand participants alternately tapped two keys on the keyboard as many times as possible and (3) using the middle and index fingers of the preferred hand participants alternately tapped two keys on the keyboard as many times as possible. Each condition consisted of 6 trials. The principal measure was ms/tap. The motor tapping task was run using the DMDX software (Forster & Forster, 2003).

Working memory measures

Subtests from the AWMA were administered. Each began with practice trials followed by test trials presented in blocks of increasing difficulty, with each block containing 6 trials. If the participant responded correctly on 4 out of 5 trials in a block the test continued to the next block. Otherwise the test was discontinued.

Verbal short-term memory was assessed using Digit Recall and Nonword Recall in which sequences of spoken digits and nonwords respectively have to be immediately repeated in the order that they were presented.

Visuo-spatial short term memory was assessed using Dot Matrix and Block Recall. Dot Matrix requires the individual to remember the location and order of dots displayed sequentially in a grid. In Block Recall, the individual views a series of blocks being tapped and reproduces the sequence in the correct order by tapping on the blocks.

Verbal executive was assessed using Listening Recall and Backward Digit Recall. In the Listening Recall task, the individual is presented with a series of spoken sentences, has to determine the veracity of the sentence and recalls the final word for each sentence in sequence. In Backward Digit Recall, the individual is required to recall a sequence of spoken digits in reverse order.

Visuo-spatial executive was assessed using Odd One Out and Spatial Recall. In the Odd One Out task the individual views three shapes, each in a box presented in a row, and identifies the odd-one-out shape. At the end of each trial, the individual recalls the location of each odd-one-out shape, in the correct order, by tapping the correct box on the screen. In Spatial Recall the individual views a picture of two arbitrary shapes, where the shape on the right has a red dot on it. The individual identifies whether the shape on the right is the same as or opposite to the shape on the left. The shape with the red dot may also be rotated. At the end of each trial the individual has to recall the location of the red dot on each shape in sequence by pointing to a picture with three compass points that represent the possible location of the red dot.

Attention measures

Selective attention was assessed using the Flanker task where participants were required to identify the direction of a central target while disregarding a number of adjacent distracters that may be congruent or incongruent to the direction of the target. The task consisted of 40 congruent and 40 incongruent trials. The congruent trials consisted of a central target (i.e., either an arrow pointing to the left or the right) and four distracters (i.e., two arrows on either side of the target) pointing in the same direction as the target. The incongruent trials consisted of a central target (i.e., either an arrow pointing to the left or the right) and four distracters (i.e., two arrows on either side of the target) pointing in the opposite direction as the target. Participants were required to identify the direction of the target (i.e., left or right) as quickly as possible by pressing the right and left shift keys respectively while ignoring the orientation of the distracters. The stimulus for each trial was displayed on the computer screen for approximately 1000ms. Participants were instructed to respond as quickly as possible to the direction of the target. The principal measures taken were mean reaction time and accuracy for congruent and incongruent trials.

Response inhibition was assessed using a Stop Signal Reaction Time task. This task had a frequent visual ‘go’ signal set up a prepotent response tendency and a less frequent visual ‘stop’ signal for participants to withhold their response. Go signals occurred on 75% of trials and stop signals on 25% of trials. The go signal followed a fixation point and participants were required to respond with a single button press when it appeared. On stop trials, the stop signal followed the onset of the go signal at different delays as outlined in Jennings, Van der Molen, Pelham, Debski and Hoza (1997) and Overtoom et al. (2002). Participants were instructed to respond as quickly as possible without making mistakes, trying not to respond on stop trials. They were instructed not to wait for the stop signal, because it occurred randomly and infrequently. The purpose of this instruction was to avoid monitoring for the stop signal. SSRT (i.e., mean time required for inhibiting responses) served as an index of response inhibition. Variability of response latencies for go-trials (i.e., SDRT) served as an index of response variability, and the proportion of trials that were successfully inhibited on stop-trials (i.e., P(*i*)) served as an index of probability of inhibition. Additionally, accuracy and response latencies on go-trials were measured.

The order of trial presentation in the selective attention and response inhibition tasks was randomised for each participant and was run using DMDX.

Testing Schedule

All tasks were administered in one session which lasted for approximately one hour, with a 5 minute break. All participants were tested in the UK.

Results

Preliminary analyses

Overall, monolinguals and bilinguals were matched on general cognitive ability and motor processing speed: groups did not differ significantly on verbal ability as measured by WASI Vocabulary (monolinguals = 63, bilinguals = 63; $F(1, 44) = .06$, $p = .81$, $\eta_p^2 = .001$), fluid intelligence (monolinguals = 60, bilinguals = 62; $F(1, 44) = 2.87$, $p = .09$, $\eta_p^2 = .06$) and motor processing speed (monolinguals = 212ms/tap, bilinguals = 227ms/tap; $F(1, 44) = 3.84$, $p = .06$, $\eta_p^2 = .08$).

Before examining group differences on the core tasks, reliability was computed for the attention tasks (Cronbach's α). The reliability of these tasks was excellent: Flanker .95 and SSRT .96. We also adopted the following criteria to reduce the effects of outliers in the Flanker task: prior to analysis erroneous responses were excluded and an inverse transformation was used to reduce the effect of remaining outliers (see Ratcliff, 1993; Ulrich & Miller, 1994). For the Stop

Signal Reaction Time task, SSRTs were estimated using the mean method (mean of inhibition function subtracted from the mean of RT distribution) as outlined by Band et al. (2003) and Verbruggen and Logan (2009).

Table 2 summarises the performance of the monolinguals and bilinguals on the eight working memory tasks and the two attention tasks.

< Insert Table 2 about here>

Working memory

Data were entered in to a multivariate analysis of variance (MANOVA), with language group as the fixed factor. Using Pillai's Trace, there was a statistically significant effect of language group on working memory, $V = .54$, $F\ (8, 37) = 5.43$, $p < .001$, $\eta_p^2 = .54$. Furthermore, separate univariate analyses of variance (ANOVA) showed that bilinguals performed significantly better than monolinguals on all 8 working memory measures (see Table 2).

Attention

Response inhibition

Data were entered in to a MANOVA, with language group as the fixed factor. Using Pillai's Trace, there was a statistically significant effect of language group, $V = .36$, $F\ (5, 40) = 4.42$, $p = .003$, $\eta_p^2 = .36$. Separate univariate ANOVA on the outcome variables showed a bilingual advantage in mean time required for inhibiting responses (i.e., SSRT). However, there were no language group differences on response latencies for go-trials, SDRT, P(*i*) and accuracy on go-trials (see Table 2).

Selective attention

RT data were entered into a 2 (*language group*: bilinguals, monolinguals) × 2 (*congruency*: congruent, incongruent) repeated measures ANOVA. As expected, in the Flanker task there was a statistically significant congruency effect (i.e., response latencies on congruent trials were significantly shorter than response latencies on incongruent trials), $F(1, 44) = 119.02$, $p < .001$, $\eta_p^2 = .73$ (see Table 2). Importantly, monolinguals and bilinguals did not differ in overall response latencies, $F(1, 44) = .90$, $p = .35$, $\eta_p^2 = .02$, and there was no statistically significant interaction between language group and congruency effect, $F(1, 44) = .56$, $p = .46$, $\eta_p^2 = .01$ (see Table 2).

Accuracy on the Flanker task was excellent (99.89%), and a 2 (*language group*: bilinguals, monolinguals) × 2 (*congruency*: congruent, incongruent) repeated measures ANOVA revealed that there was no statistically significant main effect of congruency (i.e., no difference between congruent and incongruent trials) and language group, $F(1, 44) = .98$, $p = .33$, $\eta_p^2 = .02$ and $F(1, 44) = 1.07$, $p = .31$, $\eta_p^2 = .02$, respectively (see Table 2). Similarly, the language group × congruency interaction was not statistically significant, $F(1, 44) = .00$, $p = 1.00$, $\eta_p^2 = .00$ (see Table 2), illustrating that there was no time/accuracy trade-off in task performance.

Discussion

Bilinguals showed an advantage in working memory, supporting the view that lifelong use of more than one language enhances working memory. Regarding executive control, a bilingual advantage was found in response inhibition, but not in selective attention, highlighting the notion that bilingualism modulates different aspects of executive mechanisms: bilingualism enhances the ability to inhibit ongoing responses, but has no impact on the ability to supress irrelevant perceptual information.

Experiment 2

Experiment 2 sought to replicate and extend Experiment 1 by additionally examining novel-word learning advantage in bilinguals, and the underlying skills that may contribute to this advantage. Based on the effects reported in Experiment 1 and by Papagno and Vallar (1995) we predicted medium to large magnitude effect sizes for language group differences in working memory (Cohen's $d = 1.17$), response inhibition (Cohen's $d = .56$) and novel-word learning (Cohen's $d = 1.04$; Papagno & Vallar, 1995); but a small effect in selective attention (Cohen's $d = .10$). Thus, given a minimum statistical power of .80 with α .05 a total sample size of 22, 30, 26 and 28 participants are required for the working memory, response inhibition, novel-word learning and selective attention tasks, respectively. Experiment 2 has a total of 40 participants; thus, there was adequate power to detect the predicted effects.

Method

Participants

Twenty monolingual adult speakers of English (mean age 21 years, 7 months; 10 males and 10 females) and 20 bilingual adult speakers of Hindi and English (mean age 23 years, 5 months; 14 males and 6 females) with no known hearing problems participated. The bilinguals were significantly older than the monolinguals by approximately 21 months, $t(38) = .2.93$, $p = .006$. As in Experiment 1 participants were university students studying in the UK and reported having no knowledge of Spanish. Similar to the bilinguals in Experiment 1, the bilinguals reported using English significantly more than Hindi on average, $t(19) = 5.23$, $p < .001$, $d = 2.40$. In contrast to Experiment 1, bilinguals rated their proficiency in Hindi significantly higher than their proficiency in English, $t(19) = 3.85$, $p < .001$, $d = 1.76$. Additionally, the mean ratio for the degree of bilingualism was .88 (see Table 1), and this differed significantly from a value that might be taken to indicate perfect bilingual balance, $t(19) = 2.76$, $p = .013$, $d = .62$. Reported age of initial exposure to English was 3 years, 7 months; with first exposure to English occurring in the home, approximately 10 months earlier than their exposure to English in school, $t(16) = 2.86$, $p = .01$, $d = 1.43$ (see Table 1). Bilinguals reported that they learned English through formal education and by speaking English with others. All participants recruited for this experiment were included in all analyses reported.

Design and materials

The design and materials are the same as in Experiment 1, except where differences are noted below.

Visual-verbal PAL

In this task participants learned novel names for novel objects. Forty spoken English words with low frequency ratings (see Morrison, Chappell & Ellis, 1997; Morrison, Ellis & Quinlan,

1992) were translated and recorded in Spanish by a native Spanish speaker. Ten adults (mix of bilinguals and monolinguals) with no knowledge of Spanish rated the familiarity of the Spanish words on a 5 point scale (1= not familiar, 5 = very familiar) in order to ensure that the words were not familiar. Based on these ratings, 8 spoken Spanish words were selected and were paired with 8 unfamiliar pictured objects taken from Warmington and Hitch (2014). Appendix A provides the mean familiarity ratings for the Spanish words and novel objects. The novel-word learning task consisted of three phases: *familiarization*, *training* and *test*.

During the *familiarization phase* participants were presented with each word-object pair one at a time. Each pictured object appeared one at a time on the computer screen for 5000ms while its name was simultaneously presented over headphones. Participants were instructed to repeat each name aloud during presentation. Each pair was presented across three blocks and item presentation was randomized within blocks and across participants.

Following familiarization, participants were administered the *training phase* in which each pictured object appeared one at a time on the computer screen. Participants were required to provide the name of the object. If their response was incorrect or they failed to provide a response corrective feedback was provided. This procedure was repeated until participants learned the name of the objects to criterion, that is, named 6 out of 8 objects (75%) correctly in a given trial. Participants had a maximum of 10 trials to reach criterion. Item presentation was randomized within trials and across participants. Once participants reached criterion they completed the *test phase* (i.e., object naming and object-name recognition) with no corrective feedback.

Object naming. Learning was assessed via an object naming task presented immediately after training (*immediate test*). In each case the 8 pictures were shown in a random order and the number named correctly and errors were recorded. The object naming task was administered again in second session a day later (*delayed test*), in a fresh, randomized order.

Object-name recognition. This task was presented in the delayed test only. Participants heard the novel names one at a time over headphones and had to match each name with the corresponding pictured object. Each name was presented simultaneously with a number on the computer screen. Participants had before them a sheet of paper showing the 8 learned objects and 2 novel distracter objects and had to match the object with its name by writing the number under the correct pictured object. Participants were not allowed to change their response once they moved on to the next item.

The experiment was run using DMDX software which recorded participants' responses for scoring. Item presentation across all phases was randomized for each participant. The principal measures taken were number of trials taken to reach criterion, object naming accuracy at immediate and delayed test, and object-name recognition accuracy.

Testing Schedule

There were two sessions. In session 1 participants were administered the novel-word learning task, object naming (immediate test), working memory measures and language background questionnaire. In session 2 (a day later) participants completed the object naming (delayed test), object-name recognition, attention, processing speed and general cognitive ability tasks. Sessions lasted for approximately one hour, each with a 5 minute break. All participants were tested in the UK.

Results

Preliminary analyses

Overall, monolinguals and bilinguals were matched on general cognitive ability and motor processing speed: groups did not differ significantly on verbal ability as measured by WASI Vocabulary (monolinguals = 65, bilinguals = 64; $F(1, 38) = .28$, $p = .59$, $\eta_p^2 = .007$) and motor processing speed (monolinguals = 219ms/tap, bilinguals = 233ms/tap; $F(1, 38) = 1.52$, $p = .23$, $\eta_p^2 = .04$); bilinguals tended to perform slightly better than monolinguals on WASI Matrix Reasoning (monolinguals = 59, bilinguals = 62), but this difference did not reach statistical significance, $F(1, 38) = 3.89$, $p = .06$, $\eta_p^2 = .09$.

As in Experiment 1, reliability (Cronbach's α) for our bespoke measures was good: Flanker .98, SSRT .94, novel-word learning .78. We adopted the same criteria as in Experiment 1 to reduce the effects of outliers in the Flanker task.

As the bilinguals and monolinguals differed significantly in age, when analysing language group differences on the core task (i.e., working memory, attention and novel-word learning) we entered age as a covariate.

Table 3 summarises the performance of the monolinguals and bilinguals on the eight working memory, the two attention and novel-word learning tasks.

< Insert Table 3 about here>

Working memory

Data were entered in to a multivariate analysis of covariance (MANCOVA), with language group as the fixed factor and age as a covariate. Using Pillai's Trace, there was a statistically significant effect of language group on working memory, $V = .45$, $F\ (8, 30) = 3.02$, $p = .013$, $\eta_p^2 = .45$. Furthermore, separate univariate ANOVA showed that bilinguals performed significantly better than monolinguals on 7 of the 8 working memory measures, the single exception being Listening Recall (see Table 3). There was no statistically significant effect of age on working memory, $V = .19$, $F\ (8, 30) = .86$, $p = .56$, $\eta_p^2 = .19$.

Attention

Response inhibition

Data were entered in to a MANCOVA, with language group as the fixed factor and age as a covariate. Using Pillai's Trace, age was not statistically significant, $V = .10$, $F\ (4, 34) = .96$, $p = .44$, $\eta_p^2 = .10$.

The effect of language group on response inhibition was statistically significant, $V = .34$, $F\ (4, 34) = 4.48$, $p = .005$, $\eta_p^2 = .35$. Furthermore, separate univariate ANOVA on the outcome variables confirmed a bilingual advantage in SSRT (see Table 3). Additionally, response latencies on go-trials were significantly shorter and less variable in the bilinguals than in the monolinguals (see Table 3). In contrast, language groups did not differ significantly in the proportion of stop-trials that were successfully inhibited (i.e., P(*i*)) and accuracy on go-trials (see Table 3).

Selective attention

RT data were entered into a 2 (*language group*: bilinguals, monolinguals) × 2 (*congruency*: congruent, incongruent) repeated measures ANCOVA with age as a covariate. As in Experiment 1 monolinguals and bilinguals did not differ in overall response latencies, $F(1, 37) = 2.67$, $p = .11$, $\eta_p^2 = .07$, and the language group × congruency interaction was not statistically significant, $F(1, 37) = .00$, $p = .99$, $\eta_p^2 = .00$ (see Table 3). In contrast to Experiment 1, response latencies on congruent trials did not differ significantly from response latencies on incongruent trials, $F(1, 37) = 1.69$, $p = .20$, $\eta_p^2 = .04$ (see Table 3). The covariate, age, was not statistically significant, $F(1, 37) = .56$, $p = .46$, $\eta_p^2 = .01$.

Accuracy on the Flanker task was excellent (99.87%), and a 2 (*language group*: bilinguals, monolinguals) × 2 (*congruency*: congruent, incongruent) repeated measures ANCOVA with age as a covariate revealed that there was no statistically significant main effect of congruency (i.e., no differences between congruent and incongruent trials), age and language group, $F(1, 37) = .02$, $p = .87$, $\eta_p^2 = .001$, $F(1, 37) = .09$, $p = .77$, $\eta_p^2 = .002$ and $F(1, 37) = 2.73$, $p = .11$, $\eta_p^2 = .07$, respectively (see Table 3). Similarly, the language group × congruency interaction was not statistically significant, $F(1, 37) = 2.73$, $p = .11$, $\eta_p^2 = .07$, illustrating that there was no time/accuracy trade-off (see Table 3).

Novel-word learning

Trials to criterion

A univariate ANCOVA, with language group as the fixed factor and age as the covariate showed a bilingual advantage in the number of trials taken to reach criterion, $F(1, 37) = 7.71$, $p = .009$, $\eta_p^2 = .17$ (see Table 3). However, age was not significantly related to the number of trials taken to reach criterion, $F(1, 37) = .29$, $p = .59$, $\eta_p^2 = .008$.

Object naming

A 2 (*language group*: bilinguals, monolinguals) × 2 (*test session*: immediate, delayed) repeated measures ANCOVA with age as a covariate, showed a bilingual advantage in object naming, $F(1, 37) = 12.39$, $p = .001$, $\eta_p^2 = .25$ (see Table 3). Performance did not decrease significantly between test sessions, $F(1, 37) = 1.03$, $p = .32$, $\eta_p^2 = .03$, and the language group × test session interaction was not statistically significant, $F(1, 37) = .39$, $p = .54$, $\eta_p^2 = .01$. The covariate, age, was not statistically significant, $F(1, 37) = .05$, $p = .82$, $\eta_p^2 = .001$.

Object-name recognition

Object-name recognition performance was at ceiling (99.37%). Data were entered into a univariate ANCOVA, with language group as the fixed factor and age as the covariate. Results showed no statistically significant effect of language group, $F(1, 37) = .12$, $p = .73$, $\eta_p^2 = .003$, and age, $F(1, 37) = 1.72$, $p = .19$, $\eta_p^2 = .04$, (see Table 3).

Correlation analyses

Table 4 shows the Pearson product-moment correlations between measures. Correlations were collapsed across groups in order to ascertain the general pattern of relationships between working memory, attention and novel-word learning (c.f., Gathercole, et al., 1997). A novel-word learning score was derived by averaging the number of correct responses collapsed across test delay in the object naming task (performance at immediate and delayed test correlated highly and significantly, $r = .59$, $p < .01$).

Six of the 8 working memory measures correlated moderately and significantly with novel-word learning (*r*s ranging from .34-.48, $p < .05$), the exceptions being Nonword Recall and Dot Matrix which correlated weakly and non-significantly with novel-word learning (*r*s ranging from .26-.27, $p > .05$). Novel-word learning correlated moderately with response inhibition ($r = -.34$, $p < .01$), but weakly and non-significantly with Vocabulary ($r = .11$, $p > .05$), selective attention ($r = -.10$, $p > .05$), fluid intelligence ($r = .23$, $p > .05$) and motor processing speed ($r = -.17$, $p > .05$).

Response inhibition correlated moderately and significantly with fluid intelligence, verbal and visuospatial short term memory (Digit Recall and Block Recall) and verbal and visuospatial executive (Backward Digit Recall, Odd One Out and Spatial Recall) (*r*s ranging from -.42-.45, $p < .05$). Selective attention correlated weakly and non-significantly with verbal and visuospatial short term memory and verbal and visuospatial executive (*r*s ranging from .004-.25, $p > .05$). Furthermore, selective attention correlated weakly and non-significantly with response inhibition ($r = -.004$, $p > .05$).

< Insert Table 4 about here>

A separate set of analyses showed that, for the bilinguals, the balance ratio correlated strongly and significantly with response inhibition (i.e., SSRT) ($r = .70$, $p = .001$), but weakly and non-significantly with selective attention (i.e., Flanker task) ($r = .16$, $p = .51$). These patterns of correlations augment the group differences by illustrating that bilingualism enhances the ability to stop ongoing responses, but has no additional facilitative impact on the ability to suppress irrelevant perceptual information.

Regression analyses: Predicting novel-word learning from verbal working memory and attention

We conducted regression analyses in order to determine the role of verbal working memory and attention in predicting unique variance in novel-word learning in monolinguals and bilinguals separately. The predictor variables were Vocabulary, Digit Recall, Nonword Recall, Backward Digit Recall, Listening Recall, selective attention (Flanker task) and response inhibition (SSRT), and were entered into the model in this order. The regression analysis consisted of a single step with all 7 variables entered together. Vocabulary and the verbal working memory measures were entered as a predictors given their established relationship with novel-word learning (see Gathercole & Baddeley, 1990; Gathercole et al., 1997; Papagno & Vallar; 1995).

Additionally, to address the issue of multicollinearity (i.e., two or more variables are very closely linearly related) between predictors entered in the regression analyses (c.f., Kreft & de

Leeuw, 1998) all relevant variables were standardised (i.e., converted into *z* scores) prior to analyses. Multicollinearity among the predictor variables was assessed using the variance inflation factor (VIF) and tolerance statistics. VIF scores of less than 4 indicate that the result will not significantly influence the stability of the parameter estimates (Myers, 1990). VIF scores for the predictor variables ranged between 1.14-1.55 for monolinguals and between 1.09-2.00 for bilinguals. Similarly, tolerance statistics were well above .20 (monolinguals = .64-.88; bilinguals = .49-.92) also indicating that there was no collinearity in the data (Menard, 1995). Further, given the small sample size in each group an additional bootstrapping procedure (Efron & Tibshirani, 1993; Shrout & Bolger, 2002) was applied to increase confidence in the reliability of findings. We achieved this by re-sampling with replacement 1000 samples derived from the original sample. Thus, 95% confidence intervals of unstandardized coefficients derived from bootstrap analysis are included in the regression results.

< Insert Table 5 about here>

Table 5 shows the hierarchical regression analysis for novel-word learning in monolinguals and bilinguals.

For monolinguals, the model accounted for 47.20% of the variance in novel-word learning, $F(7, 12) = 1.53$, $p = .24$, and only Listening Recall explained statistically significant unique variance.

In contrast, for bilinguals the model accounted for 72.70% of the variance in novel-word learning, $F(7, 12) = 4.57$, $p = .01$. Interestingly, not only did verbal working memory (i.e., Digit Recall and Listening Recall) explain statistically significant unique variance in novel-word learning in bilinguals, but response inhibition also accounted for unique significant variance. This pattern is consistent with the idea that enhanced executive skills underpin the novel-word learning advantage in bilinguals.

Vocabulary did not contribute statistically significant unique variance to novel-word learning in both groups. This suggests that, regardless of language status, lexical knowledge did not support novel-word learning in the present sample of young adults, perhaps reflecting our use of Spanish words that had no phonological or lexical resemblance to either English or Hindi.

Mediation analysis: Does verbal working memory mediate the relationship between bilingualism and novel-word learning?

A simple mediation model was tested to examine the extent to which verbal working memory (i.e., Digit Recall and Listening Recall), as a statistically significant unique predictor in the regression, mediated the relationship between language status (monolingual vs. bilingual) and novel-word learning. All continuous variables were converted into standardised *z* scores on the full sample to facilitate between and within-model comparisons and allow unstandardised regression coefficients to be interpreted as Cohen's *d* effect sizes when predicting from a categorical variable, in this case language status/group (Hayes, 2009). Additionally, we derived a verbal working memory composite by summing the *z* scores for Digit Recall and Listening Recall.

Mediation analysis was carried out using bias-corrected bootstrapping to minimise Type II error (Shrout & Bolger, 2002) and to establish the statistical significance of all total, direct, and indirect effects. The bootstrapping method is advantageous primarily because it increases power and was carried out using the PROCESS macro for SPSS developed by Preacher and Hayes (Hayes, 2013; Preacher & Hayes, 2008). The Preacher and Hayes bootstrapping method is a non-parametric test and as such does not violate assumptions of normality making it ideal for small sample sizes. In the analysis reported 1000 samples were derived from the original sample (N = 40) by a process of resampling with replacement. PROCESS allowed us to detect the difference between the direct effect of language status on novel-word learning, and the indirect effect after accounting for verbal working memory. Cohen's *d* effect sizes, standard errors, 95% bias-corrected confidence intervals, are shown in Figures 1 and 2.

< Insert Figure 1 about here>

Examination of the total effect (see Figure 1) showed that language status was related significantly to novel-word learning, such that bilingualism was associated with better novel-word learning prior to accounting for verbal working memory. Importantly, verbal working memory was a statistically significant, partial mediator of language status differences in novel-word learning, and accounted for 35% of the variance in the relation (see Figure 2).

< Insert Figure 2 about here>

Discussion

The results of Experiment 2 are consistent with Experiment 1: bilingual advantage in working memory (excluding Listening Recall) and response inhibition, but not in selective attention. Bilinguals outperformed monolinguals in novel-word learning, and this advantage was partially mediated by bilingual's enhanced verbal working memory capacity. Additionally, individual differences in response inhibition explained unique variance in bilingual novel-word learning.

General discussion

Our results confirm a bilingual advantage in virtually all measures of working memory (excluding Listening Recall: Experiment 2) and response inhibition (depicting medium to large effects), but not in selective attention. This is consistent with the view that the bilingual advantage in cognition is attributable to a particular pattern of strengths in executive control and working memory.

Selective attention and response inhibition correlated weakly. Response inhibition correlated moderately with working memory, while selective attention correlated weakly with working memory. These patterns are consistent with the suggestion of some commonality and diversity across executive mechanisms (Miyake & Friedman, 2012).

We found a bilingual advantage in novel-word learning, and this was true for the number of trials taken to reach criterion and their ability to recall the names both at immediate and delayed test. Instead, individual differences in response inhibition and verbal working memory explained unique significant variance in bilingual novel-word learning, but not in monolinguals. Additionally, verbal working memory was a partial mediator of differences in novel-word learning between language groups. On the basis of this preliminary evidence, we propose that the underlying cognitive characteristics of being bilingual contributed to this advantage in novel-word learning. Whilst monolinguals only activated verbal (executive) working memory, bilinguals simultaneously activated verbal short-term memory, verbal (executive) working memory and response inhibition when retrieving new words.

At first glance the present findings appear to be at odds with studies that reported no differences in attention between monolinguals and bilinguals who were university students (i.e., young adults: Bialystok et al., 2005; Gathercole et al., 2014; Paap & Greenberg, 2013). We employed two attention tasks - Stop Signal Reaction Time and Flanker tasks. Previous studies typically utilised the Simon task, which taps selective attention or interference control. The Simon and Flanker tasks are logically equivalent: both assess the participant's ability to respond to a task-relevant perceptual attribute while suppressing or ignoring a task-irrelevant attribute. However, the Stop Signal Reaction Time task is distinct from both of these in the sense that it taps the inhibition of an ongoing response (c.f., Khng & Lee, 2014). Performance on the Flanker and Stop Signal Reaction Time tasks are influenced by different cognitive processes (c.f., Khng & Lee, 2009; Livesey et al., 2006), consistent with the fact that both tasks were uncorrelated in the present study. Furthermore, we found that SSRT was highly correlated with balance ratio whereas selective attention was weakly and non-significantly correlated. Thus, our results are consistent with the argument that selective attention offers no additional processing advantage in bilinguals (see Bialystok et al., 2005; Gathercole et al., 2014; Paap & Greenberg, 2013). Moreover, our results highlight the importance of adopting multiple tasks to identify the aspects of executive processes that are enhanced in bilinguals (Paap et al., 2015).

We report a bilingual advantage in verbal and visuo-spatial working memory, extending the findings of Papagno and Vallar (1995) by illustrating that the bilingual advantage in working memory is also evident in visuo-spatial working memory. Our findings are consistent with those reported by Morales et al. (2013) and Blom et al. (2014), but differ from those reported by Engel de

Abreu and colleagues (Engel de Abreu, 2011; Engel de Abreu et al., 2012). We are confident that the differences between our findings and those reported by Engel de Abreu are not down to task differences as we used the same tasks from the AWMA as Engel de Abreu. Additionally, our results are inconsistent with those reported by Ratiu and Azuma (2015), Alternatively, we suggest that these differences may be related to sampling factors such as the heterogeneity of the bilinguals (c.f., Gasquoine et al., 2017), and as such it is vital that subsequent research considers accounting for sample heterogeneity when comparing monolinguals and bilinguals.

Additionally, working memory was significantly related to response inhibition (c.f., Namazi & Thordardottir, 2010; Unsworth & Spillers, 2010). This pattern of results is unsurprising, adding to a long-standing body of evidence that working memory is not only used for maintaining online information, but also for using that information along with contextual cues to generate imminent action (c.f., Roberts, Hager, & Heron, 1994).

We acknowledge that a closed system of learning 8 novel words is not entirely typical of word learning outside the laboratory. Nevertheless, the current findings provide insight regarding how bilinguals and monolinguals differ in terms of the underlying mechanisms they recruit to establish and retrieve novel associations from memory. Unlike previous bilingual word learning studies that teach participants the associations between a novel and a familiar word (e.g., Papagno & Vallar, 1995), our participants learned the associations between novel words and novel objects. Despite lacking ecological validity, this approach provides a useful demonstration that bilinguals acquire novel verbal information more efficiently even when there are very few contextual/situational cues to facilitate learning.

Although our findings must be interpreted cautiously due to the small sample, they nevertheless highlight that bilingualism is not a unitary construct. Furthermore, our findings shed light on the notion that associative learning mechanisms are implicated in executive control processes (Abrahamse et al., 2016), and that future research should consider testing paradigms related to the application of implicit learning in executive control.

References

Abrahamse, E., Braem, S., Notebaert, W., & Verguts, T. (2016). Grounding Cognitive Control in Associative Learning. *Psychological Bulletin, 142,* 693-728.

Adesope, O. O., Lavin, T., Thompson, T., & Ungerleider, C. (2010). A Systematic Review and Meta-analysis of the Cognitive Correlates of Bilingualism. *Review of Educational Research, 80*, 207-245.

Alloway, T. P. (2007). Automated working memory assessment. London: Pearson Assessment.

Antón, E., Duñabeitia, J. A., Estévez, A., Hernández, J. A., Castillo, A., Fuentes, L. J., …& Carreiras, M. (2014). Is there a bilingual advantage in the ANT task? Evidence from children. *Frontiers in Psychology, 5.*

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. H. Bower (Ed.), The psychology of learning and motivation Vol. 8 (pp. 47–89). New York: Academic Press.

Band, G. P., H., van der Molen, M. W., &. Logan, G. D. (2003). Horse-race model simulations of the stop-signal procedure. *Acta Psychologica 112*, 105–142.

Barac, R., & Bialystok, E. (2012). Bilingual effects on cognitive and linguistic development: Role of language, cultural background, and education. *Child Development, 83*,413–422.

Bartolotti, J., & Marian, V. (2012). Language learning and control in monolinguals and bilinguals. Cognitive Science, 36(6), 1129-1147.

Bartolotti, J., Marian, V., Schroeder, S. R., & Shook, A. (2011). Bilingualism and inhibitory control influence statistical learning of novel word forms. *Frontiers in Psychology, 2*, 324.

Blom, E., Küntay, A. C., Messer, M., Verhagen, J., & Leseman, P. (2014). The benefits of being bilingual: working memory in bilingual Turkish-Dutch children. *Journal of Experimental Child Psychology, 128*, 105-119.

Bialystok, E. (2006). Effect of bilingualism and computer video game experience on the Simon task. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 60*, 68.

Bialystok, E. (2017). The bilingual adaptation: How minds accommodate experience. *Psychological bulletin, 143*, 233.

Bialystok, E., Craik, F. I., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task: evidence from MEG. *NeuroImage, 24*, 40-49.

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology of Aging, 19*, 290–303.

Bialystok, E., Craik, F. I. M., & Ryan, J. (2006). Executive control in a modified antisaccade task: Effects of aging and bilingualism. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, 1341-1354.

Bialystok, E., Kroll, J. F., Green, D. W., MacWhinney, B., & Craik, F. I. M. (2015). Publication bias and the validity of evidence: What's the connection? *Psychological Science, 26*, 944–946.

Bialystok, E., Majumder, S., & Martin, M. M. (2003). Developing phonological awareness: Is there a bilingual advantage? *Applied Psycholinguistics,24*, 27-44.

Bialystok, E., Martin, M. M., & Viswanathan, M. (2005). Bilingualism across the lifespan: The rise and fall of inhibitory control. *International Journal of Bilingualism, 9*, 103-119.

Bialystok, E., & Viswanathan, M. (2009). Components of executive control with advantages for bilingual children in two cultures. *Cognition, 112*, 494-500.

Blaisdell, A. P., Sawa, K., Leising, K. J., & Waldmann, M. R. (2006). Causal Reasoning in Rats. *Science, 311*, 1020-1022.

Blom, E., Küntay, A. C., Messer, M., Verhagen, J., & Leseman, P. (2014). The Benefits of Being Bilingual: Working Memory in Bilingual Turkish–Dutch Children. *Journal of Experimental Child Psychology, 128*, 105-119.

Booth, J. R., Burman, D. D., Meyer, J. R., Lei, Z., Trommer, B. L, Davenport, N. D, Li, W., Parrish, T. B, Gitelman, D. R, & Mesulam, M. M. (2003). Neural development of selective attention and response inhibition. *Neuroimage, 20*, 737–751.

Bormann, T., Seyboth, M., Umarova, R., & Weiller, C. (2015). "I know your name, but not your number" – Patients with verbal short-term memory deficits are impaired in learning sequences of digits. *Neuropsychologia 72*, 80–86.

Bunge, S. A., Dudukovic, N. M., Thomason, M. E., Vaidya, C. J., & Gabrieli, J. D. (2002). Immature frontal lobe contributions to cognitive control in children: evidence from fMRI. *Neuron, 33*, 301-311.

Cenoz, J. (2003). The Additive effect of Bilingualism on Third Language Acquisition: A Review. *International Journal of Bilingualism, 7*, 71-87.

Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition, 106*, 59–86.

Cummins, J. (1976). The influence of bilingualism on cognitive growth: A synthesis of research findings and explanatory hypotheses. *Working Papers on Bilingualism, 9*, 1-43.

De Bruin, A., Treccani, B., & Della Sala, S. (2014). Cognitive advantage in bilingualism an example of publication bias? (2015). Cognitive advantage in bilingualism: An example of publication bias? *Psychological Science, 26,* 99–107.

Van Duijvenvoorde, A. C., Jansen, B. R., Griffioen, E. S., Van der Molen, M. W., & Huizenga, H. M. (2013). Decomposing developmental differences in probabilistic Feedback Learning: A Combined Performance and Heart-rate Analysis. *Biological Psychology, 93*, 175-183.

Duñabeitia, J. A., Hernández, J. A., Antón, E., Macizo, P., Estévez, A., Fuentes, L. J. & Carreiras, M. (2014). The inhibitory advantage in bilingual children revisited:

Myth or reality? *Experimental Psychology (formerly Zeitschrift für Experimentelle Psychologie), 61*, 234–251.

Efron, B., & Tibshirani, R. J. (1994). An Introduction to the Bootstrap. CRC press.

Engle, R. W. (2002). Working Memory Capacity as Executive Attention. Current *Directions in Psychological Science, 11*, 19-23.

Engel de Abreu, P. (2011). Working Memory in multilingual children: Is there a bilingual effect? *Memory, 19,* 529-537.

Engel de Abreu, P. M. J., Cruz-Santos, A., Tourinho, C. J., Martin, R., & Bialystok, E. (2012). Bilingualism enriches the poor: Enhanced cognitive control in low-income minority children. *Psychological Science, 23*, 1364-1371.

Eriksen, B.A., & Eriksen, C.W. (1974). Effects of noise letters upon the identification of a target in a nonsearch task. *Perception & Psychophysics, 16,* 143–149.

Faul, F., & Erdfelder, E. (1992). GPOWER: A Priori, Post-hoc, and Compromise Power Analyses for MS-DOS [Computer Program]. Bonn, FRG: Bonn University, Department of Psychology.

Flege, J. E., MacKay, I. R., & Piske, T. (2002). Assessing bilingual dominance. *Applied Psycholinguistics, 23*, 567-598.

Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. Behavior Research Methods, Instruments, & Computers, 35, 116-124.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General, 18*, 893–900.

Friedman, N. P., Miyake, A., Young, S. E., DeFries, J. C, Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology: General, 137*, 201–225.

Fritz, M. S., & MacKinnon, D. P. (2007). Required Sample Size to Detect the Mediated Effect. *Psychological Science, 18*, 233-239.

Gasquoine, P. G., Weimer, A. A., & Amador, A. (2017). Specificity rates for non-clinical, bilingual, Mexican Americans on three popular performance validity measures. *The Clinical Neuropsychologist, 31*, 587-597.

Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied Psycholinguistics, 27*, 513–544.

Gathercole, S. E., & Baddeley, A. D. (1990). The Role of Phonological Memory in Vocabulary Acquisition: A study of Young Children Learning New Names. *British Journal of Psychology, 81,* 439-454.

Gathercole, S. E., Hitch, G. J., Service, E., & Martin, A. J. (1997). Phonological Short-Term Memory and New Word Learning in Children. *Developmental Psychology, 33*, 966-979.

Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28*, 887 -898.

Gathercole, V. C. M., Thomas, E. M., Kennedy, I., Prys, C., Young, N., Viñas Guasch, N. V., Roberts, E. J., Hughes, E. K., & Jones, L. (2014). Does language dominance affect cognitive performance in bilinguals? Lifespan evidence from preschoolers through older adults on card sorting, Simon, and metalinguistic tasks. *Frontiers in Psychology, 5*, 11.

Green, D. W., & Abulatebi, J. (2013). Language control in bilinguals: the adaptive control hypothesis. *Journal of Cognitive Psychology, 25*, 515–530.

Hammer, A., Mohammadi, B., Schmicker, M., Saliger, S., & Münte, T. F. (2011). Errorless and errorful learning modulated by transcranial direct current stimulation. *BMC Neuroscience, 12*, 72–80.

Hayes, A. F. (2009). Beyond Baron and Kenny: Statistical Mediation Analysis in the New Millennium. *Communication Monographs, 76,* 408-420.

Hayes, J. R. (2013). The Complete Problem Solver. Routledge.

Hernández, M., Costa, A., & Humphreys, G. W. (2012). Escaping capture: Bilingualism modulates distraction from working memory. *Cognition, 122*, 37-50.

Hilchey, M. D., & Klein, R. M. (2011). Are there bilingual advantages on nonlinguistic interference tasks? Implications for the plasticity of executive control processes.

Psychonomic Bulletin and Review, 18, 625–658.

Hua, Z., & David, A. (2008). Study design: Cross-sectional, longitudinal, case, and group. *The Blackwell guide to research methods in bilingualism and multilingualism*, 88-107.

Jennings, J. R., van der Molen, M. W., Pelham, W., Debski, K. B., & Hoza, B. (1997). Inhibition in boys with attention deficit hyperactivity disorder as indexed by heart rate change. *Developmental Psychology, 33*, 308-318.

Kapa, L. L., & Colombo, J. (2013). Attentional control in early and later bilingual children. *Cognitive Development, 28*, 233-246.

Kaushanskaya, M. (2012). Cognitive mechanisms of learning in bilingual and monolingual adults: The role of phonological memory. *Bilingualism: Language and Cognition, 15*, 470-489.

Kaushanskaya, M., & Marian, V., (2009a). The bilingual advantage in novel word learning. *Psychonomic Bulletin and Review, 16*, 705–710.

Kaushanskaya, M., & Marian, V. (2009b). Bilingualism reduces native-language interference in novel word learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*, 829–835.

Khng, K. H., & Lee, K. (2009). Inhibiting interference from prior knowledge: Arithmetic intrusions in algebra word problem solving. *Learning and Individual Differences, 19*, 262–268.

Khng, K. H., & Lee, K. (2014). The relationship between Stroop and Stop-Signal measures of inhibition in adolescents: Influences from variations in context and measure estimation. *PLoS One, 9(7):* e101356.

Kirk, N. W., Fiala, L., Scott-Brown, K. C., & Kempe, V. (2014). No evidence for reduced Simon cost in elderly bilinguals and bidialectals. *Journal of Cognitive Psychology, 26*, 640-648.

Kreft, I. G., Kreft, I., & de Leeuw, J. (1998). Introducing multilevel modeling. Sage.

Livesey, D., Keen, J., Rouse, J., & White, F. (2006). The relationship between measures of executive function, motor performance and externalising behaviour in 5- and 6-year-old children. *Human Movement Science, 25*, 50–64.

Lu, C. H., & R. W. Proctor (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin and Review, 2*, 174-207.

Luk, G., de Sa, E., & Bialystok, E. (2011). Is there a relation between onset age of bilingualism and enhancement of cognitive control? *Bilingualism: Language and Cognition, 14*, 588-595.

Logan, G. D. (1994). On the ability to inhibit thought and action: a users' guide to the stop signal paradigm. In D. Dagenbach, & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language*. San Diego: Academic Press.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: a theory of an act of control. *Psychological Review, 91*, 295–327.

Martin-Rhee, M., & Bialystok, E. (2008).The development of two types of inhibitory control in monolingual and bilingual children. *Bilingualism: Language and Cognition, 11*, 81-93.

Mayringer, H., & Wimmer, H. (2000). Pseudoname learning by German-speaking children with dyslexia: evidence for a phonological learning deficit. *Journal of Experimental Child Psychology, 75*, 116-133.

Menard, S. (1993). Applied Logistic Regression Analysis, Thousand Oaks, CA: Sage.

Messbauer, V. C., & de Jong, P. F. (2003). Word, nonword, and visual paired associate learning in Dutch dyslexic children. *Journal of Experimental Child Psychology, 84*, 77-96.

Miękisz, A., Haman, E., Łuniewska, M., Kuś, K., O'Toole, C., & Katsos, N. (2017). The impact of a first-generation immigrant environment on the heritage language: productive vocabularies of Polish toddlers living in the UK and Ireland. *International Journal of Bilingual Education and Bilingualism, 20*, 183-200.

Mishra, R. K., & Singh, S. (2014). Language non-selective activation of orthography during spoken word processing in Hindi–English sequential bilinguals: an eye tracking visual world study. *Reading and Writing, 27*, 129-151.

Miyake, A. & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science, 21,* 8–14.

Morales, J., Calvo, A., & Bialystok, E. (2013). Working memory development in monolingual and bilingual children. *Journal of Experimental Child Psychology, 114*, 187-202.

Morrison, C. M., Chappell, T. D., & Ellis, A. W. (1997). Age of acquisition norms for a large set of object names and their relation to adult estimates and other variables. *Quarterly Journal of Experimental Psychology, 50A*, 528-559.

Morrison, C. M., Ellis, A. W., & Quinlan, P. T. (1992). Age of acquisition, not word frequency, affects object naming, not object recognition. *Memory and Cognition, 20*, 705-714.

Myers, R. (1990). Classical and Modern Regression with Applications. Duxbury

Press, Boston, MA.

Namazi, M., & Thordardottir, E. (2010). A working memory, not bilingual advantage, in controlled attention. *International Journal of Bilingual Education and Bilingualism, 13*, 597-616.

Overtoom, C. C., Kenemans, J. L., Verbaten, M. N., Kemner, C., van der Molen, M. W., Van Engeland, H., Buitelaar, J. K. & Koelega, H. S. (2002). Inhibition in children with attention-deficit/hyperactivity disorder: a psychophysiological study of the stop task. *Biological Psychiatry 51*, 668–676.

Paap K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology, 66,* 232-235.

Paap, K. R., Johnson, H. A., & Sawi, O. (2015). Bilingual advantages in executive functioning either do not exist or are restricted to very specific undetermined circumstances. *Cortex, 69*, 265–278

Papagno, C., & Vallar, G. (1995). Short-term memory and vocabulary learning in polyglots. *Quarterly Journal of Experimental Psychology, 48A*, 98-107.

Poepsel, T. J., & Weiss, D. J. (2016). The influence of bilingualism on statistical word learning. *Cognition, 152*, 9-19.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and Resampling Strategies for Assessing and Comparing Indirect Effects in Multiple Mediator Models. *Behavior Research Methods, 40*, 879-891.

Prior, A., & Gollan, T.H. (2011). Good Language-Switchers are Good Task-Switchers: Evidence from Spanish–English and Mandarin–English Bilinguals. J*ournal of the International Neuropsychological Society, 17*, 682–691.

Ratcliff, R. (1993). Methods of dealing with reaction time outliers. *Psychological Bulletin, 114*, 510–532.

Ratiu, I., & Azuma, T. (2015). Working Memory Capacity: is there a bilingual advantage? *Journal of Cognitive Psychology, 27*, 1-11.

Reder, F., Marec-Breton, N., Gombert, J. E., & Demont, E. (2013). Second-language learners' advantage in metalinguistic awareness: A question of languages' characteristics. *British Journal of Educational Psychology, 83*, 686-702.

Roberts, R. J., Jr., Hager, L. D., & Heron, C. (1994). Prefrontal cognitive processes: Working memory and inhibition in the antisaccade task. *Journal of Experimental Psychology: General, 123*, 374-393.

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2009). A cognitive approach to the development of early language. *Child Development, 80*, 134–150.

Shrout, P. E., & Bolger, N. (2002). Mediation in Experimental and Nonexperimental Studies: New Procedures and Recommendations. *Psychological Methods, 7*, 422.

Singh, L., Fu, C. S., Tay, Z. W., & Golinkoff, R. M. (2017). Novel Word Learning in Bilingual and Monolingual Infants: Evidence for a Bilingual Advantage. *Child Development*. DOI: 10.1111/cdev.12747

Thorn, A. S., & Gathercole, S. E. (1999). Language-specific Knowledge and Short-term Memory in Bilingual and Non-bilingual Children. *The Quarterly Journal of Experimental Psychology: Section A, 52*, 303-324.

Ulrich, T., & Miller, J. (1994). Effects of truncation on reaction time analysis. *Journal of Experimental Psychology: General, 123*, 34-80.

Unsworth, N., & Spillers, G. J. (2010). Variation in working memory capacity and episodic recall: The contributions of strategic encoding and contextual-retrieval. *Psychonomic Bulletin and Review, 17*, 200-205.

Van Hell, J. G., & Mahn, A. C. (1997). Keyword mnemonics versus rote rehearsal: Learning concrete and abstract foreign words by experienced and inexperienced learners. *Language Learning, 47*, 507-546

Verbruggen, F., & Logan, G. D. (2009). Models of response inhibition in the stop-signal and stop-change paradigms. *Neuroscience & Biobehavioral Reviews, 33*, 647-661.

Warmington, M., & Hitch, G. J. (2014). Enhancing the learning of new words using an errorless learning procedure: Evidence from typical adults. *Memory, 22*, 582-594.

Warmington, M., Hitch, G. J., Gathercole, S. E. (2013). Improving word learning in children using an errorless technique. *Journal of experimental child psychology 114*, 456-465.

Warmington, M., & Hulme, C. (2012). Phoneme Awareness, Visual-verbal Paired-associate Learning, and Rapid Automatized Naming as Predictors of Individual Differences in Reading Ability. *Scientific Studies of Reading, 16*, 45-62.

Wechsler, D. (1999). Wechsler abbreviated scale of intelligence. San Antonio, TX: Psychological Corporation.

Appendix A

Mean (SD) familiarity ratings for Spanish words

Item	Rating
Silbato	1.70 (.48)
Oruga	1.30 (.48)
Mapache	1.50 (.52)
Flauta	1.90 (.56)
Escoba	1.80 (.42)
Cincel	1.50 (.52)
Cangreho	1.20 (.63)
Alicates	1.60 (.51)

Mean familiarity ratings for novel objects taken from Warmington and Hitch (2014)

1.10

1.20

1.10

1.55

1.66

1.88

1.20

1.00

Table 1. *Mean (and standard deviation) language proficiency and language usage self-reports of bilinguals for Experiment 1 (N = 23) and Experiment 2 (N = 20).*

	Experiment 1	Experiment 2
Language Proficiency		
Hindi proficiency	6.30 (1.01)	6.40 (.94)
English proficiency	5.95 (.64)	5.55 (.60)
Balance ratio	.98 (.25)	.88 (.18)
Language Usage		
Use of Hindi in family contexts	3.48 (1.16)	4.05 (.94)
Use of Hindi with friends	3.52 (1.16)	4.15 (.67)
Use of Hindi in work/study contexts	1.39 (8.39)	1.25 (.44)
Average Usage of Hindi	*2.79 (.71)*	*3.15 (.46)*
Use of English in family contexts	3.86 (1.01)	3.33 (1.03)
Use of English with friends	4.43 (.66)	4.25 (.85)
Use of English in work/study contexts	4.82 (.49)	4.85 (.48)
Average Usage of English	*4.37 (.55)*	*4.13 (.63)*
Age of Initial Exposure to English		
Home	3 years	3 years, 2 months (1.28)
School	3 years, 11 months	4 years, 0 months (1.17)
Average Age of Initial Exposure	*3 years, 5 months*	*3 years, 7 months (.81)*

Note. Language proficiency was rated on a 7 point scale, with 1 = very poor and 7 = native like. Use of language was rated on a 5 point scale, with 1 = never and 5 = all the time.

Table 2. *Mean (and standard deviation) for working memory and attention measures for both groups with group differences (N = 46) for Experiment 1.*

	Monolinguals (N = 23)	Bilinguals (N = 23)	*F* statistic	*p* value	η_p^2
WORKING MEMORY					
Verbal STM					
Digit Recall (SS)	97 (11)	110 (14)	9.95	.003	.18
Nonword Recall (SS)	119 (8)	127 (8)	10.73	.002	.20
Visuo-spatial STM					
Dot Matrix (SS)	99 (9)	112 (12)	15.20	<.001	.26
Block Recall (SS)	100 (11)	108 (14)	4.19	.04	.09
Verbal Executive					
Listening Recall (SS)	103 (11)	113 (13)	6.744	.013	.13
Backward Digit Recall (SS)	97 (11)	116 (12)	26.98	<.001	.38
Visuo-spatial Executive					
Odd One Out (SS)	105 (9)	116 (14)	7.01	.01	.14
Spatial Recall (SS)	98 (10)	112 (11)	19.73	<.001	.31
ATTENTION					
Stop Signal Reaction Time					
SSRT (ms)	200 (108)	115 (37)	12.54	.001	.22
GORT (ms)	600 (191)	539 (105)	3.14	.08	.06
SDRT (ms)	187 (36)	195 (72)	.24	.63	.005
P(*i*) (%)	66 (11)	73 (14)	2.98	.09	.06
Go-trials Accuracy (%)	99 (1)	98 (2)	.61	.44	.01
Flanker					
RT					
Congruent	457 (71)	479 (96)	-	-	-
Incongruent	510 (67)	529 (104)	-	-	-
Congruency Effect	*53 (32)*	*50 (30)*	-	-	-
Accuracy (%)					
Congruent	99 (.52)	100 (0)	-	-	-
Incongruent	99 (.72)	99 (.52)	-	-	-

Note. df = (1,44); STM = short-term memory; SS = Standard Score; GORT = reaction time for go-trials; SDRT = standard deviation (variability) of RTs for go-trials; P(*i*) = probability of inhibition (i.e., the proportion of trials that were inhibited on stop-trials); Congruency Effect = calculated by subtracting RT on incongruent trials from RT on congruent trials; η_p^2 = partial eta squared (small effect = .01, medium effect = .09, large effect = .25).

Table 3. *Mean (and standard deviation) for working memory, attention and novel-word learning measures for both groups with group differences (N = 40) in Experiment 2.*

	Monolinguals (N = 20)	Bilinguals (N = 20)	*F* statistic	*p* value	η_p^2
WORKING MEMORY					
Verbal STM					
Digit Recall (SS)	91 (6)	104 (11)	16.47	< .001	.31
Nonword Recall (SS)	106 (16)	119 (11)	6.30	.02	.15
Visuo-spatial STM					
Dot Matrix (SS)	102 (13)	111 (8)	7.39	.01	.17
Block Recall (SS)	94 (14)	113 (16)	9.98	.003	.21
Verbal Executive					
Listening Recall (SS)	101 (11)	107 (13)	2.30	.14	.06
Backward Digit Recall (SS)	98 (15)	114 (11)	9.22	.004	.20
Visuo-spatial Executive					
Odd One Out (SS)	104 (11)	114 (11)	5.72	.02	.13
Spatial Recall (SS)	100 (13)	114 (11)	9.22	.004	.20
ATTENTION					
Stop Signal Reaction Time					
SSRT (ms)	283 (138)	123 (85)	13.48	.001	.27
GORT (ms)	684 (138)	524 (85)	13.48	.001	.27
SDRT (ms)	211 (98)	133 (29)	8.21	.007	.18
P(*i*) (%)	67 (11)	68 (11)	.20	.66	.005
Go-trials Accuracy (%)	99 (1)	99 (1)	.63	.43	.02
Flanker					
RT					
Congruent	478 (70)	515 (57)	-	-	-
Incongruent	537 (91)	575 (70)	-	-	-
Congruency Effect	*59 (32)*	*60 (24)*	-	-	-
Accuracy (%)					
Congruent	100 (0)	100 (0)	-	-	-
Incongruent	99 (1)	100 (0)	-	-	-
NOVEL-WORD LEARNING					
Trials to Criterion (Max = 10)	4.10 (1.92)	2.70 (1.08)	-	-	-
Object Naming					
Immediate (Max = 8)	5.75 (1.25)	6.75 (.72)	-	-	-
Delayed (Max = 8)	4.75 (1.37)	6.10 (.79)	-	-	-
Recognition (Max = 8)	7.90 (.45)	8 (0)	-	-	-

Note. df = (1,37); STM = short-term memory; SS = Standard Score; GORT = reaction time for go-trials; SDRT = standard deviation (variability) of RTs for go-trials; P(*i*) = probability of inhibition (i.e., the proportion of trials that were inhibited on stop-trials); Congruency Effect = calculated by subtracting RT on incongruent trials from RT on congruent trials; η_p^2 = partial eta squared (small effect = .01, medium effect = .09, large effect = .25)

Table 4. *Correlations between working memory, attention and novel-word learning collapsed across language groups (N = 40).*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Motor Processing Speed		.15	.38*	-.12	-.06	-.07	-.01	-.07	-.03	.09	.23	.16	.04	-.17
2. Fluid Intelligence			.51**	.10	.21	.25	.37*	.02	.05	.06	.06	-.42**	.23	.23
3. Vocabulary				.04	.16	.17	.004	-.11	-.18	-.02	-.12	.004	-.25	.11
4. Digit Recall					.38*	.42**	.51**	.29	.55**	.47**	.41**	-.39*	.005	.48**
5. Nonword Recall						.34*	.49**	.20	.28	.11	.23	-.25	-.18	.27
6. Listening Recall							.48**	.53**	.29	.19	.31*	-.15	-.10	.46**
7. Backward Digit Recall								.34*	.44**	.38*	.59**	-.45**	-.13	.45**
8. Dot Matrix									.55**	.48**	.41**	-.22	.24	.26
9. Block Recall										.64**	.57**	-.35*	.19	.41**
10. Odd One Out											.67**	-.37*	.06	.35*
11. Spatial Recall												-.41**	.13	.38*
12. Response Inhibition													-.004	-.34*
13. Selective Attention														-.10
14. Novel Word Learning														

Note. **p* < .05 ***p* < .01. Motor Processing Speed = Simple Reaction Time; Fluid Intelligence as measured by WASI Matrix Reasoning; Vocabulary as measured by the WASI; Response Inhibition = SSRT; Selective Attention was calculated by subtracting RT on incongruent trials from RT on congruent trials.

Table 5. *Hierarchical regression with vocabulary, verbal working memory and attention as predictors of novel-word learning in monolinguals and bilinguals (N = 40).*

Variable	Monolinguals (N = 20)					Bilinguals (N = 20)				
	B	SE B	*t*	β	95% BCa CI	B	SE B	*t*	β	95% BCa CI
Vocabulary	.007	.38	.02	.006	-.78, .86	-.02	.12	-.25	-.04	-.21, .36
Digit Recall	-.14	.41	-.47	-.11	-1.04, .95	.24	.12	2.64*	.44	.03, .40
Nonword Recall	.06	.36	.23	.05	-.67, .54	-.18	.16	-1.49	-.32	-.47, .06
Backward Digit Recall	.18	.43	2.29	.16	-.81, 1.65	-.18	.13	-1.57	-.34	-.45, .06
Listening Recall	.70	.41	.64*	.60	-.38, 1.48	.35	.14	3.05*	.64	.12, .62
Selective Attention	.09	.33	.41	.09	-.52, .75	-.20	.15	-1.79	-.32	-.5, .19
Response Inhibition	-.32	.44	-1.17	-.27	-1.39, .93	.50	.19	3.41*	.57	.07, .87

Note. *p < .05. Vocabulary as measured by the WASI; Selective Attention was calculated by subtracting RT on incongruent trials from RT on congruent trials; Response Inhibition = SSRT; B = bootstrap unstandardised coefficients; SE B = bootstrap standard error for unstandardised coefficients; β = standardised beta values; BCa CI = bias-corrected bootstrap confidence intervals.

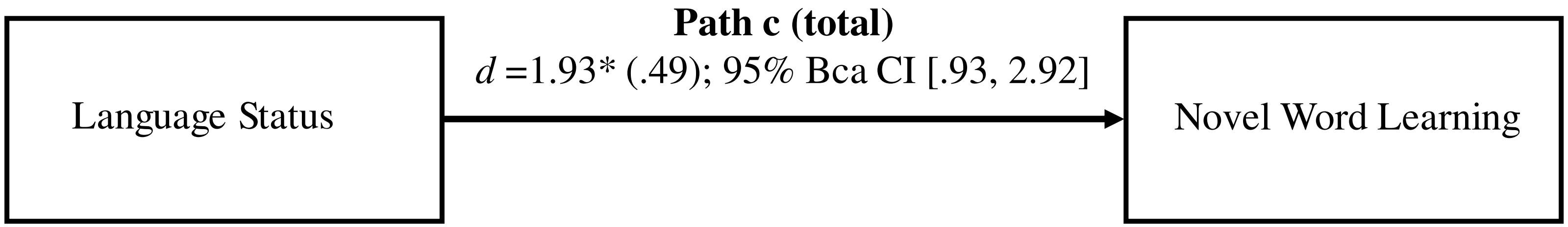

Figure 1. Schematic model depicting total effects of language status on novel-word learning. Cohen’s *d* for the c pathway reflects the impact of language status on novel-word learning before taking into account the mediating variable. Effect sizes (or β weights) are significant based on 95% BCa CI.

Note. *p < .05. Language Status = dummy coded variable: 0 - monolinguals; 1 - bilinguals; *d* = Cohen’s *d* effect size; BCa CI = bias-corrected bootstrap confidence intervals.

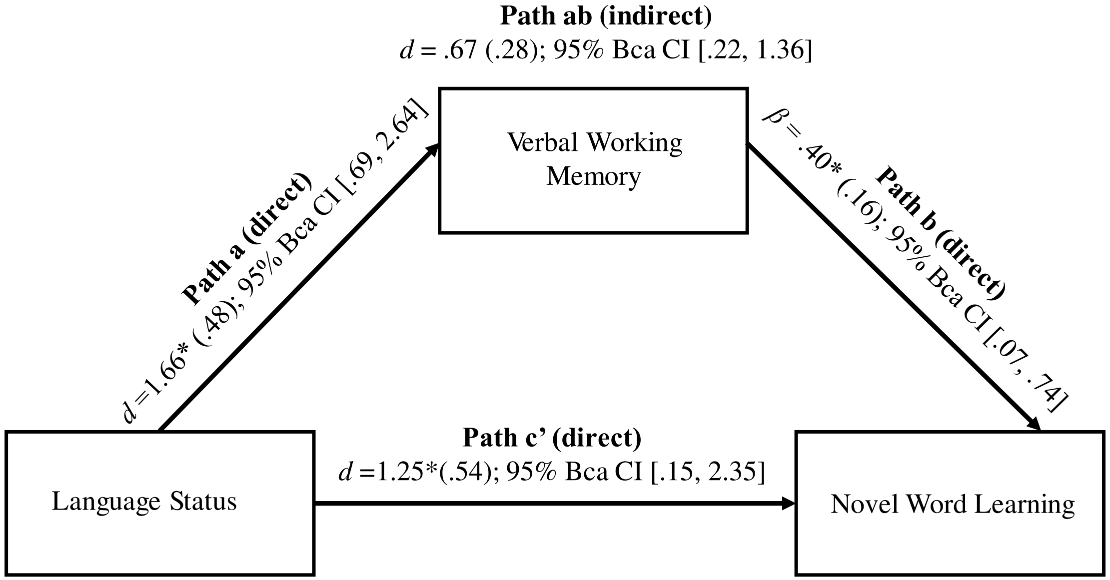

Figure 2. Schematic model depicting direct, indirect and mediating effects of verbal working memory (i.e., composite of Digit Recall and Listening Recall) on novel-word learning. Cohen's *d* for the c' pathways reflects the impact of language status on novel-word learning after taking into account the mediating variable. Effect sizes (or β weights) are significant based on 95% BCa CI. Values for path b reflect β weights due to the use two continuous variables to calculate the direct effect. Solid lines represent significant pathways.

Note. $^*p < .05$. Language Status = dummy coded variable: 0 - monolinguals; 1 - bilinguals; *d* = Cohen's *d* effect size; BCa CI = bias-corrected bootstrap confidence intervals.