Bilingualism as a Protective Factor for Executive Dysfunction in Autism

by

Alexander Kolios

Dr. Brianna L. Yamasaki
Adviser

Department of Psychology

Dr. Brianna L. Yamasaki

Adviser

Dr. Laura A. Edwards

Committee Member

Dr. Andrew M. Kazama

Committee Member

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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

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While conclusions from research are mixed, there are studies that demonstrate a bilingual advantage in executive functioning and studies that demonstrate executive *dysfunction* in individuals with autism. Despite these complementary patterns of findings, very little research has looked at the bilingual-autism experience and its effect on executive function skills. Even fewer studies have tested this population's performance on inhibitory control, the subdomain of executive functioning previously shown to be most positively impacted by bilingualism, and no studies to date have tested this population's performance on spatial working memory, the subdomain previously shown to be most negatively impacted by autism. This current study aimed to investigate this relation through three sub-studies. The first being a comparison of inhibitory control and spatial working memory skills in monolingual and bilingual adults to replicate bilingual differences in executive function. The second being a comparison of inhibitory control and spatial working memory skills in 7-8-year-old children with autism and typically developing children to replicate autism-related executive function dysfunction and demonstrate the feasibility of these tasks in these populations. And the third being the comparison of inhibitory control and spatial working memory skills in 7-8-year-old monolingual and bilingual children with autism to ultimately investigate the cognitive implications of this experience. Since data collection for Study 2 and 3 are still ongoing, only the results from Study 1 are discussed. In Study 1, no significant differences were found between the monolingual and bilingual adults on the inhibitory control and spatial working memory tasks. However, this may be due, in part, to the amount of second language exposure experienced by the "monolingual" participants and a possible "ceiling effect" of executive function skills. If one of these mechanisms is in fact contributing to the null effects, these findings would serve as further justification for Study 2 and 3 and other research with younger participants as they would be able a illustrate a much clearer picture of how these factors, namely autism and bilingualism, influence cognitive development.

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Introduction

Over the past 20 years, there has been a dramatic rise in the number of studies focusing on bilingualism and autism respectively, and in particular on the impact of these experiences on cognitive development. Much of this research has focused on the development of executive functions, a class of several domain-general cognitive skills that support goal directed behavior (e.g., Carlson et al., 2013) and have been shown to have a significant influence on academic and professional success (e.g., Richland & Burchinal, 2012). In general, studies have found a *favorable* effect of bilingualism on executive functioning, that is, either faster average reaction times or higher average accuracy on various executive function tasks for bilinguals as compared to monolinguals (e.g., Sorge et al., 2017; Carlson & Meltzoff, 2008). While other studies have found evidence of executive *dysfunction* in children with autism, that is, either slower average reaction times or lower average accuracy on various executive function tasks for children with autism as compared to children without autism (e.g., Hughes et al., 1994). Given these contrasting patterns of findings, it is unclear how bilingualism and autism may interact to influence the development of executive functions. Understanding these potential interactions is important for the growing number of bilingual families in the United States (US) who are seeking evidence-based recommendations on whether they should raise their children bilingually. Unfortunately, there is very little research available on the impact of the intersection of these lived experiences (although for some examples of this work see: Li et al., 2017; Ratto et al., 2020; Nadig & Gonzalez-Barrero, 2019; Iarocci et al., 2017). To address this gap, the current study aims to compare executive functioning skills between bilingual autistic children and monolingual autistic children. Beginning to fill this gap in prior research, will not only contribute to the growing body of work exploring how individual differences in lived experiences drive variability in cognitive development, but may also serve as a foundation on which, in combination with future work, clinical recommendations regarding whether children with neurodevelopmental disabilities should be raised bilingually can be built.

Bilingualism and Executive Functioning

Given that the number of bilinguals in the US has tripled in the past three decades, it is not particularly surprising that there has been a similar increase in research within the US focused on the impact of bilingualism on development (Grosjean, F. 2010; Dietrich & Hernandez, 2022). Multiple studies have shown a positive impact of bilingualism on the development of executive functioning skills (e.g., Carlson & Meltzoff, 2008; Yurtsever et al., 2023; Park et al., 2018; Ye et al., 2017; Chung-Fat-Yim et al., 2019). A quantitative analysis by Yurtsever et al., (2023) of 147 studies which compared executive function task performance between monolingual and bilingual children showed that across all 147 studies, the bilingual groups performed better on various executive function tasks “more often than chance.” Work like this suggests that bilingualism may lead to a “global cognitive advantage” in executive functioning. However, other studies have suggested that this potential “advantage” may be more prominent in specific subdomains of executive functioning (e.g., Nguyen et al., 2023; Antón et al., 2019; Sorge et al., 2017; Carlson & Meltzoff, 2008). Crivello et al. (2017) compared monolingual and bilingual toddlers on a variety of executive function tasks over a 7-month period and showed that the bilingual toddlers outperformed the monolingual toddlers specifically on the inhibitory control tasks. Similarly, Poulin-Dubois et al. (2011) administered a battery of executive function tasks on 63 24-month-old monolingual and bilingual children and only identified a bilingual "advantage" on the Stroop Task, a commonly used inhibitory control task.

Other studies have shown that this bilingual "effect" on inhibitory control carries on in later stages of child development, including into middle childhood, the focus of the current study (e.g., Sorge et al., 2017; Bialystok & Viswanathan, 2009; Poarch et al., 2012). Poarch et al. 2012 compared the performance of 5–8-year-old German-English bilinguals, 5-8-year-old German-English-other language trilinguals, and 6-8-year-old German monolinguals on, two inhibitory control tasks, the Simon task and the Attentional Networks Task. Consistent with many previous studies testing younger participants, the bilingual and trilingual groups showed greater inhibitory control on both tasks as compared to the monolingual group. While research into this relation in even older populations is much less abundant, various studies have nonetheless highlighted that this effect does carry into adulthood (e.g., Degirmenci et al., 2022; Luk et al., 2011; Hartanto et al. 2019; Lee Salvatierra et al., 2011; Bialystok et al., 2014).

Despite a multitude of studies pointing to a bilingual "advantage" in inhibitory control, a broader look at the research landscape in this area, shows that as a field we are far from a clear consensus on whether or not there is a bilingual "advantage" in executive functioning. Various literature reviews in this area have found a lack of substantial evidence for a bilingual "advantage" in either inhibitory control, specifically, or in executive functioning, more generally (e.g., Lehtonen et al., 2018 for adults; Lowe et al., 2021 for children). Clearly, more work is needed to better understand the more nuanced relation between bilingual language experience and individual differences in executive functioning, particularly in samples of children in middle childhood, where there is far less research in this space.

Autism and Executive Functioning

Mirroring the rise of interest in work on the impacts of bilingualism, the impact of autism on cognitive development has also become an increasingly popular topic of research due to the drastic increase of diagnoses in recent years (e.g., King & Bearman, 2009). In contrast to the work on bilingualism, various studies have found evidence of executive *dysfunction* in autistic children in comparison to their neurotypical peers (e.g., Hughes et al., 1994). Through a meta-analysis of 235 studies exploring the performance of autistic individuals across age groups on executive function tasks as compared to neurotypical individuals, Demetriou et al. (2017) found evidence for executive *dysfunction* in autistic individuals across many different executive functioning domains, including inhibition, working memory, mental flexibility, etc. This idea of a "global" executive dysfunctioning associated with autism has been supported by other work (e.g., Xie et al., 2020; Christ et al., 2010; Hughes et al., 1994). Mahdavi et al. (2017), compared 34 children with autism and 36 neurotypical children, all aged 5-16, on executive function skills using BRIEF ratings, a parent-completed survey that evaluates executive functioning through numerous subscales. Results were consistent with the meta-analysis, indicating significantly higher scores on all executive dysfunction subscales for the autistic children.

Despite this work, several reviews have pushed back against this concept of a "global" executive function impairment in those with autism, and instead have suggested the presence of a set of specific subdomain deficits (e.g., O'Hearn et al., 2008; Hill et al., 2004a; Russo et al., 2007; Russell et al., 1999). Based on a review of research in this area, O'Hearn et al. (2008)

concluded that the impact of autism on individual differences in executive functioning is most prominent within the subdomains of inhibition and working memory (see also Luna et al., 2007). While the relation between autism and inhibition is less well established (e.g., Hill et al., 2004b; Geurts et al., 2014) there is considerably more evidence for impairments in the working memory domain of executive function among those with autism (e.g., Habib et al., 2019; Gilotty et al., 2002; Rosenthal et al., 2013). In a meta-analysis that included twenty-eight studies encompassing over 1600 participants ranging from middle-childhood to well into adulthood, Wang et al. (2017) found working memory deficits in the autistic groups, but also specified that these deficits could mostly be attributed to impairments in spatial working memory, and not verbal (or phonological) working memory. Other studies have also replicated this finding of pronounced autism-related impairments in spatial working memory (e.g., Williams et al. 2005; Cui et al., 2010; Zinke et al., 2010). Williams et al. (2005), compared the performance of both neurotypical and autistic adults and adolescents on verbal and spatial working memory tasks. Across groups, the participants with autism had significantly lower scores than the neurotypical group, implying worse spatial working memory skill among those with autism. Interestingly, this was not the case for verbal working memory as there were no significant differences found on the verbal working memory task between the neurotypical and autistic participants across the adolescent and adult groups.

Despite some convincing evidence of autism-attributed executive dysfunction in spatial working memory (and perhaps also inhibition) the overall findings have been mixed. In fact, there are a number of studies that have contradicted this previous evidence and have shown that individuals with autism do possess intact spatial working memory skills (e.g. Nakahachi et al., 2006; Koshino et al., 2008; Macizo et al., 2016; Geurts et al., 2004). Therefore, there is more work to be done in substantiating claims of autism-attributed executive dysfunction, particularly in spatial working memory.

Interaction between Bilingualism and Autism on Executive Functioning

Given the research previously discussed suggesting a possible *favorable* effect of bilingualism on executive functioning, and an *unfavorable* effect of autism on executive functioning, one might theorize that the interactions of these experiences would manifest in more advanced executive functioning skills for *bilingual* children with autism as compared to *monolingual* children with autism. Yet, while these two populations and their respective trajectory of cognitive development have been moderately researched, there’s been hardly any research done on the intersection of these experiences. Of the few studies that have looked at this relation, many have found no significant differences between the monolingual and bilingual groups. However, upon a closer inspection of these studies, most of the tasks and components of executive function these studies have explored are not those that have been shown to be among the most impacted by bilingualism or autism. Instead, a majority of the previous work in this area has focused on individual differences in verbal fluency (e.g., Nadig & Gonzalez-Barrero, 2019), cognitive flexibility (e.g., Sharaan et al., 2021), or verbal working memory (e.g., Peristeri, 2020).

Li et al. (2017) is one of the only studies to have directly looked at inhibitory control, one of the subset skills within the class of executive functions that has been previously shown to be most impacted by both bilingualism (e.g., Crivello et al., 2017; Sorge et al., 2017) and autism (e.g., Demetriou et al., 2017). Li and colleagues (2017) found no difference between bilingual and monolingual children with autism, however, given that this is just one study more work in this space is definitely needed. Furthermore, the bilingual sample in Li et al. (2017) spoke Japanese and English, two languages that are vastly different which is significant because the amount of overlap in the languages bilinguals are fluent in has been found to influence performance on executive function tasks (e.g., Barac & Bialystok, 2012)

None of the available research has examined potential differences in monolingual and bilingual autistic children's performance on spatial working memory tasks, one of the subset skills within the class of executive functions in which autistic children have been shown to perform particularly worse on as compared to neurotypical children (e.g., Jiang et al., 2013). And while there has been limited exploration of a potential bilingual "advantage" in spatial working memory, there is a demonstrated relation between inhibition and spatial working memory skills (e.g., Beattie et al., 2018). Therefore, if there is a *favorable* effect of bilingualism on inhibition in children with autism, this could carry over into *favorable* effects in spatial working memory. Given that spatial working memory skills are among those most impacted by autism, if bilingual language experience could provide a "protective" or "compensatory" effect on the development of these skills, this would be particularly important to know.

This study aims to fill these gaps in the current research by comparing the performance of bilingual and monolingual autistic children on both inhibition and spatial working memory tasks. However, given the lack of substantial research regarding *favorable* bilingual effects on inhibition and spatial working memory and autism attributed-executive *dysfunction* in inhibition and spatial working memory, this exploration of the intersection of the experiences requires more foundational justification. Thus, this study was divided into three distinct but connected sub-studies, with one examining monolingual and bilingual differences in inhibition and spatial working memory skills in adults, one examining autism and neurotypical differences in inhibition and spatial working memory skills in children, and the final study attempting to answer the cumulative question of the nature of the interaction of bilingualism and autism on inhibition and spatial working memory skills.

Methods

Measures

The measures for the three sub-studies are divided into surveys and experimental tasks.

Surveys

The Language Experience and Proficiency Questionnaire. The Language Experience and Proficiency Questionnaire (LEAP-Q) is a self-report survey that is used to collect information on various aspects of an individual's language experience (Marian, Blumenfeld, & Kaushanskaya, 2007). Specifically, the adult participants (in Study 1) were asked to identify and characterize each language they have been exposed to. All individuals who reported a speaking proficiency score of 7 or higher (on a 0 to 10-point scale) in at least two languages were considered bilingual in Study 1. All individuals who reported being exposed to only English or being exposed to English and another language with a speaking proficiency score of less than 7 were considered monolingual in Study 1.

The Child Language Experience and Proficiency Questionnaire. The Child Language Experience and Proficiency Questionnaire (cLEAP-Q) is a guardian-completed-survey that is used to collect information on various aspects of a child's language experience (Marian, Blumenfeld,

& Kaushanskaya, 2007). Specifically, guardians were asked to identify and characterize each of the languages their child has been exposed to. The same proficiency criteria (reporting two languages with a speaking proficiency rating of greater than 7) was used to group each child into the monolingual or bilingual group (in Study 3).

Behavior Rating Inventory of Executive Function-2. The Behavior Rating Inventory of Executive Function 2 (BRIEF-2) is a guardian-completed questionnaire of executive function skills in children aged 5-18 years with developmental conditions (used in Study 2 & 3; Gioia et al., 2015). The purpose of the survey is to assess a child's executive functioning in home or classroom settings by asking about the frequency of executive functioning-related behaviors in those contexts. The survey evaluates eight subscales of executive functioning: inhibit, self-monitor, shift, emotional control, working memory, plan/organize, organization of materials, and monitor. In addition to the subscales, the survey also results in an overall score, called the Global Executive Composite score which compiles and summarizes all of the subscale scores. The Global Executive Composite score "T score" ranges from 0 to 100 with scores from 60 to 64 representing mildly impaired executive function skills, 65 to 69 representing potentially clinically impaired executive function skills, and scores 70 and above representing clinically impaired executive function skills.

Experimental Tasks

Backwards Corsi Block Task. The Backwards Corsi Block Task measures spatial working memory skill (Milner, 1971). All participants (both adults and children) completed the same version of this task, in which they were visually presented with an array of 9 orange flowers. On each trial, 3-6 orange flowers turned red, one at a time. Following the presentation of the red flowers, participants were asked to indicate, using the mouse, the reverse order in which the red flowers appeared. Prior to the experimental blocks, participants completed two practice blocks in which three red flowers appeared and they were asked to indicate in forward order (Block 1) or backwards order (Block 2) the flowers that appeared. All participants completed four blocks of 5 trials, in which 3, 4, 5, or 6 red flowers, respectively, appeared per trial. Participants received scores based on the number of trials for which they were able to answer completely correct, with a maximum score of 20. Better spatial working memory skills are reflected by higher scores on this Backwards Corsi Block Task. To be included in the final analysis, participants had to correctly answer at least 2 of the first five trials (in which three red flowers appeared on each trial). Two versions of this task were created in which a different randomized sequence was used for the red flower presentation. Each participant completed only one version of the task.

Simon Task. The Simon Task (Simon, 1969) is a frequently used inhibition task which generates an overall score called the Simon Effect. Both adults and children completed the same version of this task. In this task, cars and trucks were visually presented on either the left or right side of the screen and participants were asked to then respond via a button press as to whether a car or truck was presented [e.g., if CAR press ‘6’ (right side); if TRUCK, press ‘A’ (left side)]. Prior to the experimental blocks, participants completed two practice blocks of twelve trials, with the first presenting the cars and trucks in the middle of the screen and the second block presenting both congruent and incongruent trials (to be described subsequently). All participants completed two experimental blocks of 32 trials each. Across the task, 75% of trials were congruent in that the shape was presented on the corresponding side of the screen that aligned with the task rule (e.g., ‘CAR’ presented on the RIGHT) and 25% of trials were incongruent in that the shape was presented on the side of the screen that conflicted with the task rule (e.g., 'CAR' presented on the LEFT). For each participant, overall Simon Effects were calculated by subtracting average congruent reaction time from average incongruent reaction time (Reaction Time Simon Effect) and by subtracting average incongruent accuracy from average congruent accuracy (Accuracy Simon Effect), with lower Simon Effects being indicative of greater inhibitory control. To be included in the final analysis, participants had to correctly answer at least 50% of the congruent trials across both experimental blocks. Two versions of this task were created in which a different randomized sequence was used for the car and truck presentation. Each participant completed only one version of the task.

Study 1: Adult Monolinguals vs. Bilinguals

To provide further support for executive function differences between monolinguals and bilinguals, the first study compared inhibition and spatial working memory task performance between adult monolingual and bilingual participants using *t*-tests. Exploratory correlation analyses were also conducted to investigate potential relations between characteristics of bilingual language experience (specifically, second-language "age of acquisition", "current exposure", and "combined speaking and understanding proficiency" from the LEAP-Q) and performance on the Simon Task and Backward Corsi Block Task.

Hypotheses.

S1H1: If the different lived experience of bilinguals in comparison to the experience of monolinguals "favorably" impacts inhibitory control, then the bilingual group will significantly outperform the monolingual group on the inhibition task. This will be reflected by smaller Simon effects on the Simon task in the bilingual group compared to the monolingual group.

S1H2: If the "favorable" impact of bilingualism extends to other areas of executive functioning, then the bilingual group will significantly outperform the monolingual group on the spatial working memory task. This will be reflected by higher scores on the Backwards Corsi Block task in the bilingual group compared to the monolingual group.

Study 2: Neurotypical vs. Autistic Children

The second study has several purposes, with the first being a demonstration of the ability of autistic children in middle childhood to complete the selected inhibition and spatial working memory tasks. Additionally, this study aims to provide further support for executive function differences between neurotypical and autistic children by comparing inhibition and spatial working memory task performance between neurotypical and autistic children using *t*-tests.

Hypotheses.

S2H1: If autism is associated with executive dysfunction in inhibitory control, then the neurotypical group will significantly outperform the autistic group on the inhibition task. This will be reflected by smaller Simon effects on the Simon task in the neurotypical group compared to the autistic group.

S2H2: If autism is associated with executive dysfunction in spatial working memory, then the neurotypical group will significantly outperform the autistic group on the spatial working memory task. This will be reflected by higher scores on the Backwards Corsi Block task in the neurotypical group compared to the autistic group.

Study 3: Bilingual Autistic vs. Monolingual Autistic Children

The third and final study will test the potential interaction between bilingualism and autism on cognitive development by comparing inhibition and spatial working memory task performance between monolingual-autistic children and bilingual-autistic children, using *t*-tests.

Exploratory correlation analyses will also be conducted to investigate relations between characteristics of bilingual language experience (from the cLEAP-Q) and performance on the Simon Task and Backward Corsi Block Task and overall scores on the BRIEF-2.

Hypotheses.

S3H1: If bilingualism acts as a "protective factor" against autism-related deficiencies in inhibitory control, then the bilingual group will significantly outperform the monolingual group on the inhibition task. This will be reflected by smaller Simon effects on the Simon task in the bilingual group compared to the monolingual group.

S3H2: If the "protective factor" of bilingualism in those with autism extends to other areas of executive functioning, then the bilingual group will significantly outperform the monolingual group on the spatial working memory task. This will be reflected by higher scores on the Backwards Corsi Block task in the bilingual group compared to the monolingual group.

S3H3: If the "protective factor" of bilingualism extends more broadly to executive functioning in general, then the bilingual group will exhibit significantly lower levels of executive dysfunction on the BRIEF-2 compared to the monolingual group. This will be reflected by lower Global Executive Composite scores on the BRIEF-2 in the bilingual group compared to the monolingual group.

Results

Data collection for Study 2 and 3 are still ongoing, so the following results and discussion only pertain to Study 1.

Participants (N = 25) ranged between 18 and 29 years old, with an average of 21.6 years old (SD = 1.98). Within the monolingual group (n = 12), participants were an average of 21.3 years old (SD = 1.37), while the bilingual group (n = 13) was 21.8 years old on average (SD = 2.44). Seven of the participants identified “Male” as their sex assigned at birth, with the other 18 participants identified as “Female.” Four participants were of Hispanic, Latino, or Spanish origin, 12 identified as Asian, 5 identified as Black or African American, and 10 identified as White. Across all participants, 19 indicated that their native (first) language was English, while the other 6 participants reported a non-English native language. Three participants specified that they also had a second native language, meaning they learned their first two languages simultaneously (see Table 1 for demographic and language characteristics).

Table 1
Demographic Characteristics by Language Group

	Bilingual (*N*=13) M (SD)	Monolingual (*N*=12) M (SD)	Total (*N*=25) M (SD)
Age (years)	21.80 (2.44)	21.30 (1.37)	21.60 (1.98)
Gender (% female)	61.50% (*N* = 8)	83.30% (*N* = 10)	72.00% (*N* = 25)
Race/Ethnicity	Asian (*N* = 10) Black or African American (*N* = 1) White (*N* = 2) Hispanic, Latino, or Spanish Origin (*N* = 1)	Asian (*N* = 2) Black or African American (*N* = 4) White (N = 8) Hispanic, Latino, or Spanish Origin (*N* = 3)	Asian (*N* = 12) Black or African American (*N* = 5) White (N = 10) Hispanic, Latino, or Spanish Origin (*N* = 4)
English Age of Acquisition (years)	5.08 (4.48)	0.75 (1.06)	3.00 (3.93)
English Exposure (%)	58.00 (18.06)	92.58 (11.15)	74.60 (23.04)
English Speaking Proficiency (0-10)	8.85 (1.14)	10.00 (0.00)	9.40 (1.00)

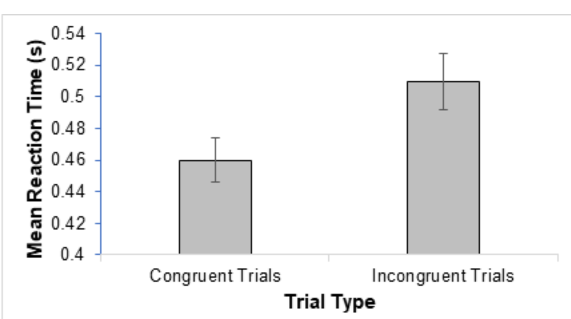
English Understanding Proficiency (0-10)	9.23 (0.83)	10.00 (0.00)	9.60 (0.71)
English Combined Speaking & Understanding Proficiency (0-10)	9.04 (0.95)	10.00 (0.00)	9.50 (0.83)
Non-English Age of Acquisition (years)	1.15 (2.03)	7.90 (4.86)	4.09 (4.86)
Non-English Exposure (%)	28.77 (15.56)	5.57 (8.44)	17.63 (17.14)
Non-English Speaking Proficiency (0-10)	9.31 (1.11)	3.67 (2.39)	6.60 (3.39)
Non-English Understanding Proficiency (0-10)	9.46 (0.97)	4.83 (3.10)	7.24 (3.23)
Non-English Combined Speaking & Understanding Proficiency (0-10)	9.38 (1.02)	4.25 (2.62)	6.92 (3.25)

Simon Task

As a group, participants showed a significant Simon Effect in both reaction time, $t(48) = -2.27$, $p < .05$; $d = 0.62$ (medium), and accuracy, $t(48) = 3.42$, $p < .05$; $d = 0.95$ (large), with shorter average reaction times and higher average accuracy in the Congruent condition (see Figures 1-4 and Table 2). Additionally, there were no significant differences observed between the two versions of the Simon Task in either average condition reaction time or accuracy (*p*s > .3).

Figure 1

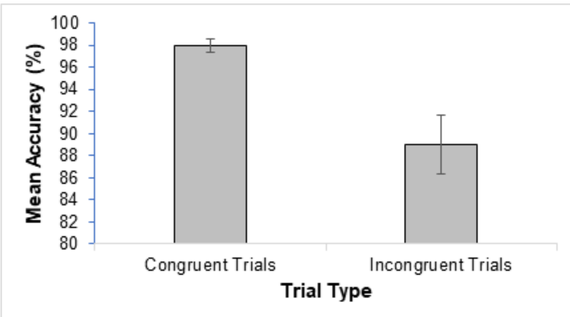
Congruent vs. Incongruent Trial Reaction Times



Note. Average congruent trial and average incongruent trial reaction times for correct trials in seconds. Error bars = standard error of the mean.

Figure 2

Congruent vs. Incongruent Trial Accuracy



Note. Average congruent trial and average incongruent trial accuracy in percentage. Error bars = standard error of the mean.

Table 2

Simon Task Performance

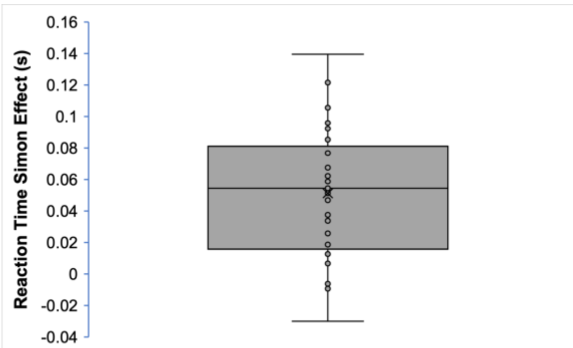
	Bilingual (*N*=13) M (SD)	Monolingual (*N*=12) M (SD)	Total (*N*=25) M (SD)	Group Difference *t*	Group Difference *p*-value
Congruent Trial RT (seconds)	0.44 (0.07)	0.48 (0.07)	0.46 (0.07)	1.38	0.18
Incongruent Trial RT (seconds)	0.50 (0.08)	0.52 (0.10)	0.51 (0.09)	0.56	0.58
RT Simon Effect (seconds)	0.06 (0.02)	0.04 (0.06)	0.05 (0.04)	-0.95	0.36
Congruent Trial Accuracy (%)	99.00 (3.00)	98.00 (3.00)	98.00 (3.00)	-0.55	0.59
Incongruent Trial Accuracy (%)	91.00 (11.00)	86.00 (16.00)	89.00 (13.00)	-0.83	0.42

Accuracy Simon Effect (%)	8.00 (9.00)	11.00 (13.00)	9.00 (11.00)	0.84	0.41

Note. RT = Reaction Time

Figure 3

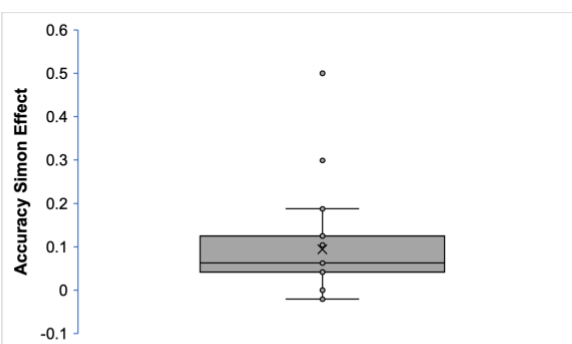
Reaction Time Simon Effect Distribution



Note. Reaction time Simon Effect scores in seconds across all participants. Reaction time Simon effects were calculated by subtracting participants' reaction time on the congruent trials from the incongruent trials.

Figure 4

Accuracy Simon Effect Distribution



Note. Accuracy Simon Effect scores in proportion of correct selections across all participants. Accuracy Simon Effects were calculated by subtracting participants' accuracy in responding on the incongruent trials from the accuracy responding on the congruent trials.

Backwards Corsi Block Task

Across the entire Backwards Corsi Block Task, participants answered an average of 13.75 trials correctly out of 20 total trials (see Table 3). Within each set-size (3, 4, 5, and 6) participants showed progressively worse accuracy as the set-size increased. Specifically, participants correctly answered on significantly more trials with the smaller vs. larger set sizes, with an average of 9 correct trials during the first two blocks and an average of 4.83 correct trials during the last two blocks, $t(46) = 8.35$, $p < .05$; $d = 2.41$ (large). Additionally, there were no significant differences in overall average score observed between the two versions of the Backwards Corsi Block task ($p = .90$).

Table 3

Backwards Corsi Block Task Performance by Language Group

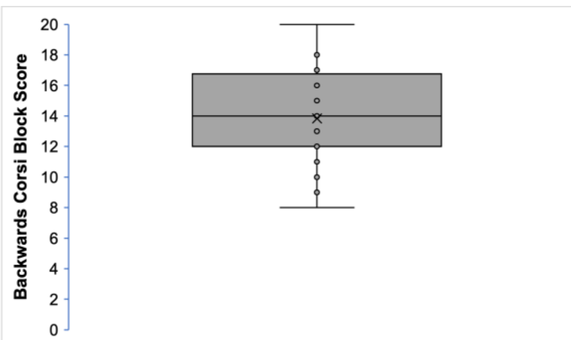
	Bilingual (*N*=12) M (SD)	Monolingual (*N*=12) M (SD)	Total (*N*=24) M (SD)	Group Difference *t*	Group Difference *p*-value
First Block Score (0-5)	4.83 (0.58)	4.58 (0.79)	4.71 (0.69)	-0.88	0.39
Second Block Score (0-5)	4.0 (0.60)	4.58 (0.51)	4.29 (0.62)	2.55	0.02
Third Block Score (0-5)	3.25 (0.60)	3.42 (1.38)	3.33 (1.46)	0.27	0.79
Fourth Block Score (0-5)	1.17 (1.11)	1.83 (1.40)	1.50 (1.29)	1.29	0.21
Early Block Scores (0-10)	8.83 (0.83)	9.17 (1.03)	9.0 (0.93)	0.87	0.39
Late Block Scores (0-10)	4.42 (2.02)	5.25 (2.49)	4.83 (2.26)	0.90	0.38

Overall Score (0-20)	13.25 (2.70)	14.42 (3.42)	13.83 (3.07)	0.93	0.36

Note. One bilingual participant's results were removed due to not meeting the minimum threshold of answering at least 2 of the first five sequences correctly. "Early Block" would be the first and second blocks while "Late Block" would be the third and fourth blocks.

Figure 5

Backwards Corsi Block Score Distribution



Note. Number of correctly answered trials on Backwards Corsi Block across all participants.

Group Comparisons

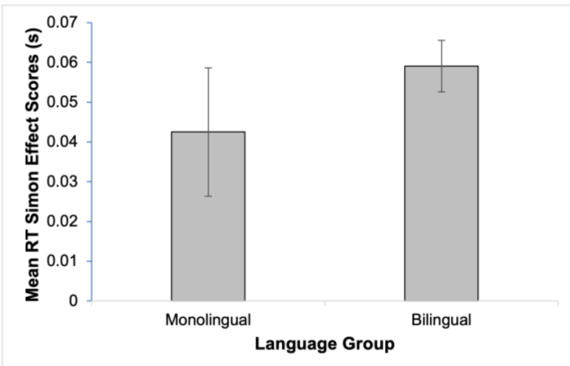
Simon Task

Within each group, both monolinguals and bilinguals showed a Simon Effect in accuracy, $t(22) = 2.52$, $p < .05$; $d = 1.36$ and $t(24) = 2.29$, $p < .05$; $d = .90$, respectively. Both the effect size for the monolingual accuracy comparison ($d = 1.36$) and for the bilingual accuracy comparison ($d = .90$) were found to exceed the Cohen's (1988) convention for a large effect ($d = .8$). However, neither the monolingual or the bilinguals showed a Simon Effect in reaction time, $t(22) = -1.20$, $p > .05$; $d = .49$ and $t(24) = -2.06$, $p = .0504$; $d = .81$, respectively, although the effect sizes were moderate to large and the p-value for bilinguals was only marginally greater than the .05 threshold. Across groups, there were no significant differences in the magnitude of the Simon Effect in reaction time, $t(23) = -.95$, $p > .05$; $d = .34$ (see Figure 6), or in accuracy, $t(23)$

= .84, *p* > .05; *d* = .39 (see Figure 7). Both the effect size for the reaction time Simon effect comparison (*d* = .34) and for the accuracy Simon effect comparison (*d* = .39) were found to meet the Cohen's (1988) convention for a small effect (*d* = .2).

Figure 6

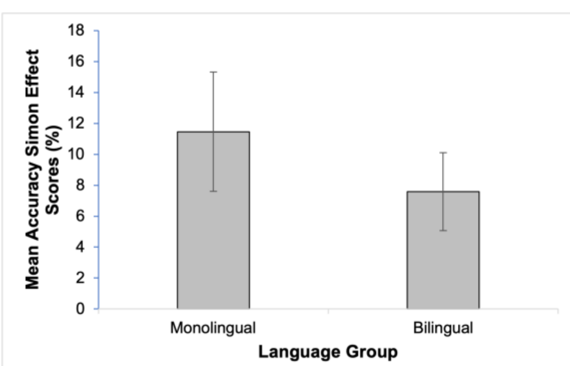
Average Reaction Time Simon Effect by Language Group



Note. Average reaction time Simon Effect scores in seconds across each language group. Reaction time Simon effects were calculated by subtracting participants' reaction time on the congruent trials from the incongruent trials. Determining participants' monolingual/bilingual status was made based on responses on the LEAP-Q, with specific criteria specified above. Error bars = standard error of the mean.

Figure 7

Average Accuracy Simon Effect by Language Group



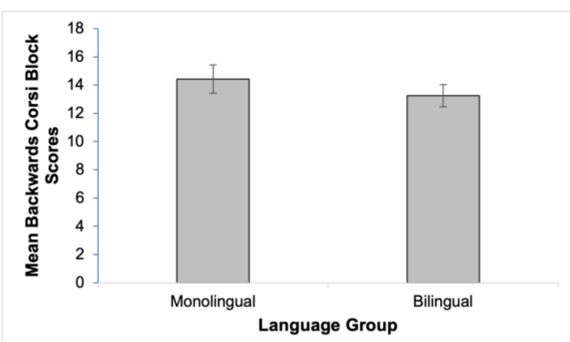
Note. Average accuracy Simon Effect scores in proportion of correct selections across each language group. Accuracy Simon Effects were calculated by subtracting participants' accuracy in responding on the incongruent trials from the accuracy responding on the congruent trials. Determining participants' monolingual/bilingual status was made based on responses on the LEAP-Q, with specific criteria specified above. Error bars = standard error of the mean.

Backwards Corsi Block Task

Within each group, both monolinguals and bilinguals answered significantly more correct trials in the early blocks (first and second), than the later blocks (third and fourth), $t(22) = 5.03$, $p < .05$; $d = 2.05$ (large) and $t(22) = 6.99$, $p < .05$; $d = 2.86$ (large), respectively. Across groups, there were no significant differences in the number of correctly answered trials on the Backwards Corsi Block, $t(22) = 0.93$, $p > .05$; $d = .38$ (see Figure 8). Error bars = standard error of the mean.

Figure 8

Average Backwards Corsi Block Score by Language Group



Note. Average number of correctly answered trials on Backwards Corsi Block across each language group. Determining participants' monolingual/bilingual status was made based on responses on the LEAP-Q, with specific criteria specified above.

Language Experience Factors Exploratory Correlations

Correlation analyses were conducted between several response categories on the LEAP-Q and performance on each of the executive function measures using Bonferroni adjusted alpha levels of .0167 per test (.05/3). Second language age of acquisition, as self-reported on the LEAP-Q, was not found to be correlated with the Simon Effect in reaction time, $r(21) = .22$, $p = .31$, the Simon Effect in accuracy, $r(21) = .05$, $p = .83$, or scores on the Backwards Corsi Block Task, $r(20) = .33$, $p = .13$. Second language "current exposure" (as defined as the self-reported percentage of time currently exposed to the second language) was also not found to be correlated with the Simon Effect in reaction time, $r(23) = .27$, $p = .19$, the Simon Effect in accuracy, $r(23) = .12$, $p = .58$, or scores on the Backwards Corsi Block Task, $r(22) = .32$, $p = .12$. The same pattern was also found with second language combined speaking and understanding proficiency, as no significant correlations were found with the Simon Effect in reaction time, $r(23) = .41$, $p = .04$, the Simon Effect in accuracy, $r(23) = .01$, $p = .96$, or scores on the Backwards Corsi Block Task, $r(22) = .21$, $p = .33$.

Discussion

Despite relatively mixed findings regarding *favorable* effects of bilingualism on executive functioning skills, there is still a robust foundation of studies that provide both theoretical and experimental evidence to suggest that young bilinguals may possess superior executive function skills to young monolinguals (e.g., Bialystok et al., 2014; Carlson & Meltzoff, 2008; Yurtsever et al., 2023; Park et al., 2018; Chung-Fat-Yim et al., 2018) and that this effect could carry on into adulthood. We aimed to replicate these findings in young adults, and in particular, with inhibitory control and spatial working memory skills.

Simon Task Findings

With this foundation of literature in mind, the first hypothesis was that the nature of bilingual language experience in comparison to that of monolinguals would lead to superior inhibitory control skills, exhibited on a Simon Task. Although within each group participants did not show a significant Simon effect in reaction time, both groups did show a Simon effect in accuracy. This provides validation that the Simon Task designed for this study is capable of capturing individual differences in inhibitory control skills. In line with the prediction, numerically bilinguals answered quicker and more accurately than monolinguals on both incongruent and congruent trials, however, inconsistent to the prediction, there were no significant differences between groups. To investigate the possibility that the null effects could be attributed to the overall faster reaction times displayed by the bilingual group, Simon Effects that were normalized over average overall reaction time were computed and compared between groups. In comparing these normalized Simon Effects, again, no significant differences between the monolingual and bilingual groups were found.

Backwards Corsi Block Task Findings

Research documenting *favorable* effects of bilingualism on spatial working memory are more limited than research on inhibitory control, however, studies have highlighted positive relations between inhibitory control and spatial working memory (e.g., Beattie et al., 2018). Given this relation, in the second hypothesis it was predicted that the bilingual group would have significantly higher spatial working memory skills than the monolingual group, as exhibited on a Backwards Corsi Block Task. Both the monolingual group and the bilingual group performed significantly better on the early trials with less locations to remember than the later trials with more locations to remember, suggesting that, as intended, spatial working memory load increased over the course of the task and the task was capable of characterizing individual differences in spatial working memory skill. Contrary to the prediction, the monolingual participants had a numerically higher average number of correct responses as compared to the bilingual group, although this difference was not significant.

In this study participants were only rewarded a point if they responded to a sequences that was fully in the correct order. However, in other studies, participants are rewarded points for each individual selection they make correctly within a trial. The approach used in the current study reduced the variability in scoring in that responses that are only one selection away from being completely correct are treated as the same as responses with no correct selections, even if they demonstrate different levels of spatial working memory capability. To evaluate the impact of these different scoring methods, performance on the Backwards Corsi Block Task was rescored based on the alternative method used in prior studies, with each individual selection being scored rather than each trial as a whole. With this alternative scoring method, again, no significant differences between the monolingual and bilingual groups were found.

Second Language Experience in 'Monolingual' Participants

While the observed pattern of results is inconsistent with the study predictions, the findings are consistent with several other prior studies showing no significant differences in executive functioning between monolinguals and bilinguals (for a review see Lehtonen et al., 2018 for adults; Lowe et al., 2021 for children). It may be the case that bilingual language experience has no meaningful impact on executive functioning skills in young adulthood, however, it is also possible that the specific demographic profiles of the participants in the current study additionally contributed to the null findings. All of the participants apart from two in the current study indicated that they had had prior experience with another language. Thus, although 12 participants were considered “monolingual”, a majority of those participants have had prior language training. If bilingual language experience does indeed positively impact executive functioning skills, then these “monolinguals” with language learning experience could have accrued some of that positive impact as well. This would lead to no (or smaller) differences between the groups, as was seen in the present work. The high degree of second-language exposure in the “monolingual” group in the present work was partially driven by the fact that a relatively strict criteria was used for bilingualism. That is, in order to be considered “bilingual” participants had to report an average speaking proficiency of 7 or greater in two languages. Other work that has used a similarly strict criteria has also failed to find significant language group differences in executive functioning (e.g., Duñabeitia et al., 2014; Colzato et al., 2008; Flavin, 2020). Flavin (2020) set a very high criteria for qualifying as bilingual, only qualifying individuals who attested to having at least a 70% proficiency rate in their second language. In line with the findings of this study, Flavin (2020) found no significant differences between bilinguals and “monolinguals” in working memory. On the other hand, but still consistent with this interpretation, other studies that have set less strict criteria have found significant differences (e.g., Antón et al., 2019; Chung-Fat-Yim et al., 2019). Chung-Fat-Yim et al. (2019) tested potential inhibitory control differences between monolingual and bilingual adolescents. Participants were determined to be monolinguals when they reported less than 25% speaking and writing proficiency in a second language in. In this study, significant group differences were found with bilinguals showing stronger inhibitory control skills.

This idea that even moderate amounts of training in a second language could accumulate executive function benefits and lead to 'monolinguals' performing relatively similarly on executive function tasks to 'bilinguals' is reinforced by the work of Durand López (2021). Durand López (2021) explored executive function differences in college-aged monolinguals, intermediate second language learners, advanced second language learners, simultaneous bilinguals, and multilinguals. Criteria for the intermediate second language learners were ratings of 4-8 on a ten-point scale for second language speaking, listening, and reading. In this current study, the criteria for bilinguals was a 7 on the LEAP-Q eleven-point scale for second language speaking, which means that a large proportion of 'intermediate second language learners' in Durand López (2021) would have been considered monolingual in this study. On the spatial working memory tasks, intermediate second language learners significantly outperformed monolinguals, suggesting that even moderate amounts of second language training could accumulate executive function advantages.

Taken together, these previous studies clearly demonstrate that the criteria used for 'monolingualism' and 'bilingualism' is a significant contributing factor as even slight experience with a second language without achieving complete fluency may have an impact on executive function skills. Future research that has more robust samples should consider a more nuanced classification of language groups, in line with the work of Durand López (2021), to better understand the influence of bilingual language experience on executive functioning skills.

Ceiling Effect

Another demographic factor that may have impacted the findings in this study is that young adulthood is known to be a time in which executive functioning skills peak. Given that all of the participants in this study were young adults there may have been a "ceiling effect" in executive functioning skills. While in the current study there was not a "numerical" ceiling effect on any of the tasks, this explanation could still apply from a theoretical perspective. That is, given that we know that young adults are at their peak in their executive functioning abilities, it is possible that there is no room left for bilingual experience to further contribute to individual differences at this age. This does not mean that there will be no variability in these skills (as would be reflected by numerical ceiling effects), but rather that the contributing factors to that variability may be different in this age range. This potential explanation is consistent with previous work comparing inhibitory control skills in samples ranging from childhood to later adulthood. Bialystok et al. (2005) found that the bilingual vs. monolingual differences, with superior performance among the bilinguals, was present in children, adulthood, and later adulthood, but not the young adult/college-age samples. Bialystok and colleagues reasoned that the lack of differences in this young adult sample was due to participants in this sample reaching a ceiling effect in inhibitory control, leaving no room for any positive effect on their inhibition skills (for similar evidence of ceiling effect in inhibitory control see also Enge et al., 2014; Bilaystok et al., 2004).

A similar relation was also found by Bialystok et al. (2014), who measured spatial working memory as well as inhibitory control skills among college-aged and older adult-aged mono- and bilinguals. Their results revealed that for both the inhibitory control and spatial working memory measures, the older bilinguals demonstrated a significantly higher bilingual advantage than the younger bilinguals. These findings, coupled with evidence from Hale et al. (2011) that illustrates a significant decline in spatial working memory skills from age 20 and onwards, indicates the suggestion of a ceiling effect in young adulthood for spatial working memory, in addition to the ceiling effect for inhibitory control as proposed by Bialystok et al. (2005).

If there is a ceiling effect for both inhibitory control and spatial working memory in college-aged young adults, this could explain the lack of significant differences in executive function skills for the monolingual and bilinguals groups in the current study, especially considering the high scores of all participants collectively the task, particularly on the Simon task.

Limitations

Reflecting on the first study, there are several aspects of both the sample recruited and details of the executive function tasks that may limit the internal and external validity of the study. Firstly, regarding the sample of participants, beyond the already mentioned issues of group criteria and age, there is a lack of representation in both language history and demographics. A large proportion of the participants had experience with Mandarin in particular, which is not representative of the broader bilingual community. This dominance of Mandarin experience in the bilingual participants is also relevant because the overlap of Mandarin with English is very little, which is a factor shown to be impactful on executive function skills (e.g., Barac & Bialystok, 2012). Given that all of the participants were either recruited from liberal college/university communities, all of the participants had very similar levels of education experience, which means the sample has a lack of diversity in terms of education, and possibly socioeconomic status, another factor shown to be influential in the development of executive function skills (for a review see Lawson et al., 2018). Another significant limitation is the lack of a substantial sample size for either the monolingual or bilingual group, with only 12 monolingual participants and 13 bilingual participants. Small sample sizes results in low power to detect potential groups differences, as evidenced by several moderate to large effect sizes in the current study, there are likely some patterns of results that were not able to be captured in the present work.

Implications

The broader quandary of exploring potential executive functioning differences between monolingual and bilingual children with autism was based on evidence from several studies of *favorable* bilingual impacts on executive function and particularly inhibitory control, and the evidence from several studies of executive *dysfunction,* particularly with spatial working memory, in children with autism. On face value, this current study's null findings not only contradict these previous studies indicating the *favorable* bilingual impacts on executive function but may be taken as evidence that Study 2 and 3 are not worthwhile efforts. However, as laid out in the previous sections, there is substantial reason to believe that the lack of differences between the monolingual and bilingual groups in Study 1 may have been driven by demographic factors that would not be (or could be made not) relevant to Study 2 and 3. In the case of attributing the results to the presence of second language experience in 'monolinguals', findings from this study add to the growing body of research on the effect of even moderate amounts of language learning on cognitive development and specifically executive functioning. To account for this finding, in Study 3, the criteria for bilingualism could be adjusted to better represent the nuanced relation between second-language experience and variability in executive functioning skills. Attributing the results to ceiling effects in college-aged individuals would not impact Study 2 and 3, as in both cases the focus is on middle childhood.

Conclusion

The lack of significant differences between the monolingual and bilingual adult participants on the Simon Task and the Backwards Corsi Block Task in Study 1, implies that these two groups do not differ in inhibitory control or spatial working memory skills. In theory, this would align with the previous research that suggests that there is not a bilingual “advantage” in executive function skills, or at least in specifically inhibitory control and spatial working memory skills in early adulthood. This interpretation would certainly lay doubt on the motivation for Study 3 because if there is no bilingual “advantage,” there would be no mechanism to moderate the theorized executive dysfunction in autism as hypothesized. However, as mentioned above, it is believed that the lack of significant differences can be explained by the level of second language exposure in the monolingual participants and/or the potential of a ceiling effect in executive function skills in young adults. If the results are able to be attributed to either of these explanations, it would not contradict the bilingual “advantage” theory and instead would serve as evidence for the concept that any level of second language training can accumulate executive function benefits or for the concept that the bilingual “advantage” in executive is dependent on the stage of development. In addition, it would not cast doubt on the justifications for the subsequent studies, and if anything, testing these relations in children in Study 2 and 3 has the ability to allow one to start to tease apart the influence of these potential contributing fact

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