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RESEARCH ARTICLE

Bilingualism and flexibility in task switching

A close replication study

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Abstract

This study aimed to closely replicate Wiseheart et al. (*Bilingualism: Language and Cognition*, 19(1), 141–146, 2016) by investigating the transferability of language-switching skills to nonlinguistic task switching. Current evidence is mixed and there is a need to conduct robust replications in this area. Bilingual (n = 31) and monolingual (n = 47) young adults characterized stimuli by either colour or shape based on a given cue. Modifications include online data collection (as opposed to in-person) and adapting the nonverbal intelligence test used. All other aspects of the study mirror those by Wiseheart et al. Results indicate that the bilinguals exhibited better cognitive flexibility in task switching, as evidenced by a reduced global switch cost compared with monolinguals. In contrast, mixed evidence was found for local switch costs. Findings mirror those reported by Wiseheart et al. and suggest that by employing comparable task-switch paradigms and recruiting samples matched on several key variables, including age, gender, variety of languages spoken, and use of English, bilingualism does seem to confer broader executive function advantages. Findings are discussed in relation to theoretical implications to inform future replication studies and advance the bilingual advantage in the switching debate.

Keywords: Bilingual advantage; bilingualism; executive control; executive functioning; replication; task switching

A significant body of literature proposes that bilingual and multilingual individuals are afforded some distinct advantages over their monolingual counterparts (Adesope, Lavin, Thompson, & Unegrleider, 2010; Bialystok, 2017; Bialystok & Martin, 2004; Costa, Hernández, & Sebastián-Gallés 2008). These advantages include a range of general improvements in executive functioning and executive control tasks, which have been observed in children (Barac, Bialystok, Castro, & Sanchez, 2014; Bialystok, 2015; Bialystok & Martin, 2004) and adults (Adesope et al., 2010; Costa et al., 2008). These findings are interpreted from the distinct demands of language control and switching required to be a competent bilingual speaker. As a result, it is suggested that this frequent inhibiting, monitoring (updating), and switching may extend to a general advantage in nonlinguistic executive functioning and executive control.

Several theories have been developed to explain the mechanisms underpinning this apparent bilingual advantage, such as the inhibitory control model (Green, 1998) and the overlap hypothesis (Paap et al., 2017; for an overview, see Paap, 2019). These claims of a bilingual advantage are substantiated by neuroimaging studies, which have been conducted as a means of examining any differences in the neural processes that may indicate detectable evidence of this bilingual advantage (Abutalebi et al., 2012; García-Pentón, Pérez Fernández, Iturria-Medina, Gillon-Dowens, & Carreiras, 2014). Researchers have reported that there are qualitative differences observed in the brain when it comes to executive functioning. For example, studies have reported modification of the structural organization of the brain, particularly in regions associated with language processing and monitoring (e.g., superior frontal gyrus and the anterior cingulate cortex), and more efficient use of brain regions, compared with monolingual controls (Abutalebi et al., 2012; García-Pentón et al., 2014).

The proposal that the linguistic control bilinguals require may confer more general nonlinguistic cognitive benefits seems plausible as executive functioning is considered domain-general (Grundy, 2020). This would align with the proposal that the linguistic control needed by bilingual individuals might confer broader cognitive advantages beyond language. In other words, the proposal suggests that the mental control exercised (executive functioning skills) by bilinguals to manage multiple languages could positively affect cognitive abilities beyond just language-related tasks. It has been suggested that this may be due to neuroplasticity, whereby bilingualism may induce neuroplastic changes, leading to adaptations in brain networks involved in both language control and executive functioning (Diamond & Shreve, 2019), monitoring the language environment (Lehtonen, Fyndanis, & Jylkkä, 2023; Rubin & Meiran, 2005) or suppressing or inhibiting interference from the other language (Declerck & Koch, 2022).

However, it is unclear how much overlap exists when processing linguistic and nonlinguistic stimuli, and neuroimaging studies suggest that different brain regions may be activated depending on the type of stimuli being processed (Fedorenko, Duncan, Kanwisher, 2012). Findings in this field are exceedingly mixed, and researchers have yet to reach a consensus on this issue (for a review, see Bialystok, Craik, Green, & Gollan, 2009; Lehtonen, Soveri, Laine, Järvenpää, de Bruin, & Antfolk, 2018). Several explanations have been proposed for the discrepancy of these findings, which include demographic variables such as age (Valian, 2015; Ware, Kirkovski, & Lum, 2020) and socioeconomic status (Morton & Harper, 2007), the task itself (Ware et al., 2020), and importantly how bilingualism is defined or measured (de Bruin, 2019). Additionally, others have proposed a publication bias in this area (de Bruin, Treccani, & Della Sala, 2015).

To move this field forward, one reasonable approach is to conduct robust replication studies to build confidence in the reliability of the current evidence in the field and ensure that previous findings are not due to sampling errors. Initial replication studies have emerged in Bilingualism (Poarch, 2018). At the same time, Psychology has been shifting toward producing reproducible research, focusing on open and transparent research practices (Shrout & Rodgers, 2018), particularly in research areas needing more evidence to substantiate previous claims or question possible false positive results. The present study aims to replicate a well-known and highly cited study published by Wiseheart, Viswanathan, and Bialystok (2016), which documented a bilingual advantage in task switching specifically, using a similar protocol, population, and analysis procedure.

Bilingualism and executive functioning

As mentioned, different executive functioning tasks have yielded mixed results. This might be due to the distinct domains that underlie executive functioning, namely inhibition (or inhibitory control), shifting (or cognitive flexibility), updating, and working memory, where each may tap into different cognitive processes. Even so, conflicting findings have emerged for each domain, with studies failing to find evidence of a bilingual advantage in all three domains (Arizmendi et al., 2018; Paap & Greenberg, 2013; Ratiu & Azuma, 2015). Of these domains, the executive functioning processes underlying bilingual processing are particularly related to task switching, with bilingual speakers required to adapt to the language environment quickly and switch tasks (language) without compromising processing speed.

This language switching is thought to involve several domains of executive functioning, namely inhibition (by suppressing the alternative language; Declerck & Koch, 2022), monitoring (by updating information in working memory; Lehtonen et al., 2023), and domain-general switching (Lehtonen et al. 2023). This rationale is the foundation of studies showing that bilinguals outperform monolinguals in task-switching paradigms (Bialystok & Martin, 2004; Prior & Macwhinney, 2010; Wiseheart et al., 2016). Furthermore, the measures used to detect advantages in task switching (described later) typically display higher test–retest reliability than other measures used to observe the proposed bilingual advantage and therefore should provide more consistent evidence to resolve this debate (Paap & Oliver, 2016).

Task switching refers to the capacity to focus attention on a singular task within a task involving two possible options and switching focus from one task (or set of rules) to another. This enables an accurate, task-specific response (Wiseheart et al., 2016). The time taken to switch these cognitive resources in task-switching paradigms has been used to calculate an individual's "switch cost." Researchers typically calculate switch cost by reporting the difference in reaction times associated with the switch and nonswitch trials. It is assumed that this switch cost provides an objective means of measuring an individual's difficulty (i.e., cost) in using cognitive resources to switch from one task to another and is referred to as a local switch cost (LSC). It has been proposed that the switch cost (i.e., the additional time and cognitive resources) may reflect the engagement of cognitive flexibility or shifting processes involved in switching from one task or set of rules to another (Lehtonen et al., 2023; Soveri, Rodriguez-Fornells, & Laine, 2011).

A second type of switch cost observed is called a global switch cost (GSC; or a mixing cost), calculated as the difference in reaction times between single-task blocks and nonswitch trials in mixed-task blocks. It is believed that each switch cost is associated with a different executive control process. Soveri et al. (2011) noted that the cognitive mechanisms underlying mixing costs are widely debated. Some suggest that these GSCs are more closely associated with more general cognitive control processes required when monitoring the task type and resolving this ambiguity (Rubin & Meiran, 2005). Others propose that mixing costs may reflect sustained attentional control and increased working memory load (Rubin & Meiran, 2005; Soveri et al., 2011), whereas others emphasize the role of monitoring as being central to these mixing costs (Lehtonen et al., 2023). Neuroimaging studies also support the claim that LSC and GSC are associated with different executive control processes, with functional magnetic resonance imaging studies demonstrating that different brain regions are activated when undertaking tasks by tapping into each switch type (Braver, Reynolds, & Donaldson, 2003).

Studies investigating whether bilinguals display reduced switch costs (i.e., more efficient task switching) have reported that when compared with monolinguals, bilinguals benefit from enhanced cognitive flexibility in task switching (Prior & Macwhinney, 2010; Wiseheart et al., 2016). For example, Prior and Macwhinney conducted a task-switching study with young bilingual adults and found that they had a reduced LSC compared with monolinguals, which was mediated by working memory capacity. In contrast, Wiseheart et al., (2016) reported an advantage for GSC but not LSC. Supporting this is an earlier study by Bialystok and Martin (2004), who reported that bilinguals not only switch between tasks more efficiently than monolinguals but also make fewer errors during these tasks. This suggests that bilinguals might have better monitoring abilities and more efficient switching skills as better switchers would be expected to respond more quickly and accurately, especially on switch trials. This enhanced accuracy is also supported by further research (Hartanto & Yang, 2019; Teubner-Rhodes, Bolger, & Novick, 2019).

Researchers have attempted to provide further evidence to strengthen the claim that these observed advantages in general task switching are specifically related to the cognitive mechanisms underpinning language switching. This includes the finding that the frequency of language switching (Prior & Gollan, 2011) and the age of acquisition (Prior & Macwhinney, 2010) is related to task-switching performance. In contrast, language proficiency per se, may not be the key determinant of the bilingual advantage observed for task switching (Verreyt, Woumans, Vandelanotte, Szmalec, & Duyck, 2016). However, others have questioned this, whereby executive functioning skills have been found to relate to individual differences observed in L2 proficiency (Gallo Novitskiy, Myachykov, & Shtyrov, 2021; Lehtonen et al., 2023). Furthermore, Calabria Hernández, Branzi, and Costa (2011) found different switch-cost patterns in relation to linguistic and nonlinguistic tasks, suggesting that bilingual language control is not wholly related to domain-general executive control mechanisms.

However, these findings have not been found for all studies employing task-switching paradigms, calling into question the reliability and generalizability of these findings. For example, both Hernández, Martin, Barceló, and Costa (2013) and Paap and Greenberg (2013) attempted to replicate Prior and Gollan's (2011) task-switch study closely. Both studies failed to find a GSC or LSC, providing mixed evidence for this effect, with neither study reporting a GSC advantage.

In contrast to this study, one of the most recent studies reported a GSC advantage but no LSC advantage for young bilingual adults (Wiseheart et al., 2016). This study recruited 68 young adults, comprising 31 bilinguals (bilingual in various languages) and 37 monolinguals. A computerized task-switching paradigm was used, which included nonswitch and switch blocks where participants were required to respond to stimuli by colour (red or blue) or shape (cow or horse). The authors reported a GSC advantage with a medium effect size. This study has significantly affected this field and is highly cited; however, given the discrepancies reported, a close replication of this study would provide further evidence of this apparent bilingual advantage in task switching.

The original study

As described, the study by Wiseheart and colleagues intended to investigate the effect of bilingualism on task-switching efficiency in young adults. The justification for the study was that there is contrasting evidence in relation to the effects of bilingualism on task switching, as outlined earlier. Specifically, Wiseheart et al.'s study intended to contribute to this field by examining the two types of switch cost (LSC and GSC), with the hypothesis that reduced GSC would be observed due to the constant need to resolve interference between the stimulus and required response. This view was taken as all trials in the original study were response-incompatible, meaning each trial required a response with a conflicting or competing response available. This contrasted with previous studies in the field where remapping was only required after 50% of the trials (as in Garbin et al., 2010 and Gold, Kim, Johnson, Kryscio, & Smith, 2013). No specific prediction was made regarding LSC in Wiseheart et al.'s study.

The original study reported a bilingual advantage wherein there was a reduced GSC found for the bilinguals compared with monolinguals. Importantly, as the original authors noted, their findings contrasted with previous studies, which did not find a GSC benefit in young adult bilinguals (such as Gold et al., 2013). Consequently, there is a need to explore this discrepancy between studies. The current study sought to closely replicate the study conducted by Wiseheart et al. (2016) to validate these findings. This is a key study to replicate, given that a bilingual advantage was found, to confirm that this result is not a false positive. Additionally, this is a feasible study to conduct a replication of given the ability to recreate the same task that was employed by Wiseheart and colleagues and the ability to access a similar target population (young adults). In the context of our study, a close replication was an attempt to reproduce the previous study's methods and procedures as closely as possible, aiming to confirm the original findings under similar experimental conditions. This approach involved closely adhering to the original study's protocols, including using highly similar experimental tasks, stimuli, and data collection procedures, as detailed here.

The replication study

As specified, the current replication study adopted a similar task protocol and target population (young adults) as in the original study. The primary difference between this replication and the original study is that the current study was conducted entirely online. In contrast, Wiseheart and colleagues conducted a computerized task in a lab setting. The replication was conducted online for several reasons. First, it allowed us to validate earlier in-person studies and examine the results' robustness and generalizability across different data collection modes. Additionally, online recruitment and data collection enhanced the accessibility for participants, enabling a diverse and representative sample. Finally, data collection occurred toward the end of the COVID-19 pandemic, where conducting the study online still provided a safe and practical alternative for data collection. The only other divergence from the original study was the choice of nonverbal intelligence test used (described later) as the second edition of the Kaufman Brief Intelligence Test (KBIT-2) is designed as an in-person assessment. Given that the replication was conducted online, the choice of a nonverbal intelligence test reflected the need to conduct the study online.

As in the original study, the participants comprised young adults, primarily university students. The primary analysis procedure also followed that of Wiseheart et al., although additional analyses have been conducted for completeness and to reflect the most suitable analysis approach. As per Wiseheart et al.'s study, it was hypothesized that the present study would replicate the finding that young adults are afforded advantages in the executive control process associated with a reduced GSC compared with monolinguals.

Methods

Participants

An initial sample of 92 participants were recruited for the study. For the replication, young adults were included if they were between 18 and 25 years. Those who self-reported only elementary proficiency in English were removed (n = 3) as their English-language proficiency did not meet the inclusion criteria of at least basic working proficiency in English, defined as being "able to handle most social situations." This was required to ensure they could accurately answer the questions regarding their language background. A further three participants were removed as their accuracy was below 70% on the pure block trials, and after checking and removing outliers (n = 8; defined as performance ±3 SD on the pure block or switch blocks), this resulted in a final sample of 78 participants.

This sample comprised 31 bilinguals (80.65% female) and 47 monolinguals (66% female). The sample size obtained for the study was determined by needing to recruit at least a comparable number of participants as the original study (68 participants) while also achieving sufficient statistical power to detect any potential differences between the groups. Participants were predominantly female (Table 1). The mean age for the bilingual participants was 20.26 years (SD = 1.57), similar to that of the monolingual participants 20.51 (SD = 1.57). The age of the groups was very similar to the original study by Wiseheart et al., who reported mean ages of 19.1 and 19.2 for monolinguals and bilinguals, respectively. Participants were recruited through the university student participant pool (n = 59) and via advertisements on social media (n = 19) to recruit members of the public. This is again similar to the sample recruited for the

Table 1. Demographic characteristics for bilingual and monolingual groups

Demographic	Bilingual	Monolingual
Gender		
Men	16.13	31.92
Women	80.65	65.96
Prefer not to say	3.23	0
Other	0	2.13
Education		
Secondary education	3.23	2.13
College/Sixth form	80.65	85.11
Undergraduate university degree	9.68	12.77
Postgraduate university degree	3.23	0
Other	3.23	0
Occupation		
Full–time student	77.42	72.34
Part–time student	0	2.13
Full–time student + part–time employment	9.68	17.02
Part–time employment	3.23	0
Full–time employment	3.23	4.26
Unemployed	6.45	2.13

Note: Data is reported in %.

original study who were also university students. Table 1 presents further demographic information.

Bilingual participants spoke a variety of other languages (N = 24) as well as English. This is comparable to the sample recruited by Wiseheart et al. who reported that the bilingual participants were variable in their second language (with 19 languages being noted). Thirteen bilinguals in the current study and Wiseheart et al.'s study reported that English was their first language. Fifteen spoke English at home (48.39%), and 25 (80.65%) used English during their education. This again suggests that the present sample was comparable to the original study, where Wiseheart et al.'s participants used English "48% of the time at home and in social settings." As reported on a shortened version of the Language and Social Background Questionnaire (LSBQ; Anderson, Mak, Keyvani Chahi, & Bialystok, 2018), bilinguals reported a high degree of proficiency in their first (M = 9.90, SD = 0.39) and second language on a scale from 1 to 10 (M = 8.94, SD = 1.24). Unfortunately, as the original study by Wiseheart and colleagues did not provide details of the participants' second-language (L2) proficiency, it is impossible to decipher how the L2 proficiency of the participants compared.

Monolingual participants were all speakers of English and were asked to answer additional questions to confirm that they had not received substantial and sustained exposure to another language. Importantly, there was no statistically significant difference between groups on age (p =.489) or nonverbal cognitive abilities (p =.631), as measured by a relational reasoning task. Similarly to the replicated study (Wiseheart et al., 2016), gender distribution was not balanced, with a higher representation of women in both bilingual and monolingual groups.

Materials

Questionnaires

A general demographics questionnaire was administered to obtain background information about the participants, as well as information as to whether they would be considered bilingual. Additionally, an adapted version of the LSBQ (Anderson et al., 2018) was used to assess the participants' language proficiency, confidence, and frequency of language use. This questionnaire also provided information about the participant's age of exposure to each language and the context in which they acquired their languages. Those who did not identify as bilingual were asked to provide information about various contexts where they may have had some exposure to additional language learning (e.g., during education or for travel purposes).

Nonverbal intelligence

As a departure from the method used by Wiseheart et al. to assess nonverbal intelligence, the current study used a standard relational reasoning task, which was administered via the Gorilla Experiment Builder (Anwyl-Irvine, Massonnié, Flitton, Kirkham, & Evershed, 2020). This decision was made due to the replication being conducted online. As the KBIT-2 used by Wiseheart was administered as an in-person assessment, this was unsuitable for the present study.

The nonverbal intelligence assessment aimed to ensure that both groups were comparable in their general intelligence. Therefore, the relational reasoning task was deemed appropriate for this purpose. Relational reasoning tasks are designed to assess the ability to identify relationships between stimuli using mental representation. Participants were presented with an array of images where one item was missing from the sequence. Four picture options were provided, and participants were asked to select the image they thought completed the sequence. There were four practice trials in which feedback was given for correct or incorrect responses. There were 15 test items where no feedback was provided. Participants were given 20 s to complete each trial before being timed out and automatically progressing to the next trial. The task difficulty increased as the task progressed.

Task-switching paradigm

As a replication study, every effort was made to align the current task-switching paradigm with the one employed by Wiseheart et al. (2016). In all task-switching trials, participants were required to respond to stimuli by colour (red or blue) or shape (horse or cow) by responding via a keyboard. The task-switching tasks comprised three blocks, two pure blocks where participants were required to respond to only colour or only shape, followed by a switch block, with participants being asked to categorize the stimuli by either colour or shape, according to a specific cue. Each pure block contained 22 trials, and the presentation of these was counterbalanced, such that half of the participants completed the colour block first, and the other half completed the shape block first. The switch block contained 56 trials. This resulted in switch and nonswitch trials within the switching block. Correct responses on trials without switch were averaged to calculate the nonswitch in switch-block reaction time. Similarly, trials containing a switch were averaged to obtain the switch in switch block reaction time.

Mirroring Wiseheart et al.'s design, all trials in both the switch and pure blocks contained two response stimuli, presented at the top of the screen with the target stimulus in the center. The task cue was presented below the target stimulus, and as in Wiseheart et al., this was either a colour wheel or a black squiggle outline (Figure 1). There was no time limit on the trials, with the stimuli and task cue remaining on the screen until a response was made. There was a 450-ms interval between each trial. This interval was slightly reduced by Wiseheart et al. to produce a robust switching cost, as studies suggest that longer intervals between trials reduce switching costs (Meiran, Chorev, & Sapir, 2000). Every trial was response-incompatible, meaning competing or conflicting response options were present.

The task-switch paradigm was recreated for the present replication study by using the example stimuli provided by the original study's authors and the detailed descriptions provided in the initial study. The materials were designed to closely mirror those of the original study, which included the same colour for the colour trials (red and blue) and the same animals (cow and horse). The figures used in the current study were clearer than those in Wiseheart et al. However, all other aspects of the materials were the same.

Design

The study design comprised a 2 x 2 mixed design, with language status as the between-group variable (bilingual vs. monolingual) and reaction times for block type (switch block vs. nonswitch block) as the within-group variable. The study employed a quasi-experimental design as participants completed a series of online tasks but were naturally allocated into bilingual and monolingual groups based on responses to the background questionnaires described here. This design is identical to that of Wiseheart

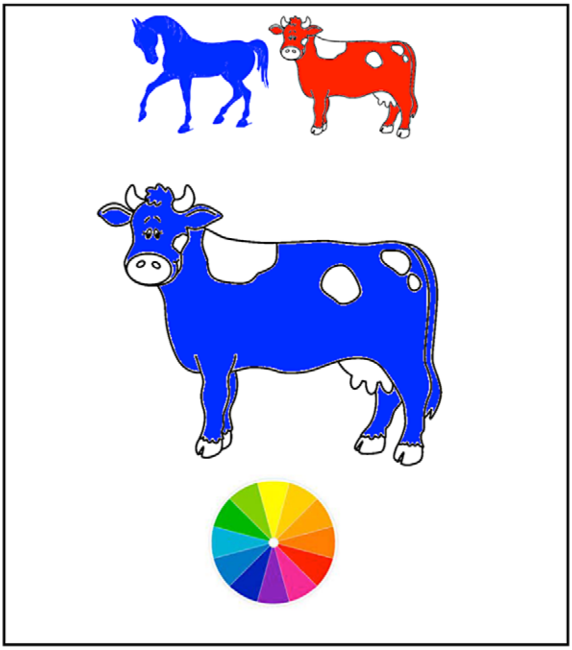

Figure 1. Example trial of the task switching paradigm.
Note: The colour trials used a colour wheel. A black squiggle outline was used as the task cue for the shape trials.

et al. (2016), except that the present study was conducted fully online instead of in a lab setting.

Procedure

As noted here, as a slight departure from Wiseheart et al., the study was completed entirely online instead of in person (although both studies employed a series of computer-based tasks). Participants were directed to Gorilla (a cloud-based experiment builder), where they were provided with the study information and required to provide informed consent. Subsequently, participants completed the demographics and language background questionnaires, the relational reasoning task, and the task-switching blocks. The two pure blocks preceded the task-switching block. Upon completion, participants received a debrief and were provided contact details if they wished to withdraw their data. Before data collection, full ethical approval was obtained from Swansea University Psychology's Ethics Committee.

Data coding and analysis

Reaction time data was extracted from the Experimental Builder (Gorilla) and reported in milliseconds (ms). Outliers were removed for any data points ±3 SD from the mean, calculated by converting data points to z scores. Only trials with correct responses were included for all analyses, which was the case for the original study. For the replication study, the analysis followed the procedure undertaken by Wiseheart et al., which included a series of analyses of variance (ANOVAs) and *t* tests. Bayesian analyses and correlations of self-reported switching frequency were also conducted for completeness. To determine the replicability of the effects observed in the original study, the present study compared LSC and GSC for monolinguals and bilinguals, which was calculated as detailed in the introduction section. These analyses allowed us to ascertain whether the observed effects in our replication study were consistent with those reported in the original study.

Results

Table 2 reports descriptive statistics for reaction times on the pure and mixed blocks. It provides a breakdown of reaction times for the switch and nonswitch trials within the switch block.

To investigate GSC, performance on the nonswitch trials in switch blocks and the nonswitch block trials (pure blocks) was analyzed using reaction times. To replicate the analysis conducted by Wiseheart et al., a 2 x 2 block type (nonswitch trials in switch blocks vs. nonswitch block trials) by language status (bilinguals vs. monolinguals) ANOVA was conducted. A main effect of block type was found [F(1,76) = 125.97, $p < .001$, $\eta^2p = .62$], with slower reaction times for the switch block compared to the pure block. There was no main effect of language status [$F(1, 76) = 0.384$, $p = .384$, $\eta^2p = .010$]. A significant interaction was found between block type and language status [$F(1, 76) = 4.063$, $p = .047$, $\eta^2p = .051$], with a larger global switch cost found for monolinguals. As can be seen in Figure 2, this interaction is observed as monolinguals were slightly quicker in the pure block, whereas bilinguals were faster in the switch block.

A further analysis of GSC was undertaken by calculating switch costs individually for each participant. Mean reaction times on the nonswitch trials in switch blocks were

Table 2. Mean reaction times for each language group in milliseconds for pure blocks (shape and colour) and mixed blocks (nonswitch and switch trials)

	Monolingual, m (SD)	Bilingual, m (SD)
Colour block RT	597.98 (180.77)	806.16 (937.25)
Shape block RT	874.81 (410.97)	783.65 (397.63)
Switch trials RT	1632.81 (588.31)	1418.37 (515.76)
Nonswitch trials RT	1318.97 (498.95)	1185.51 (449.63)

RT = reaction time.

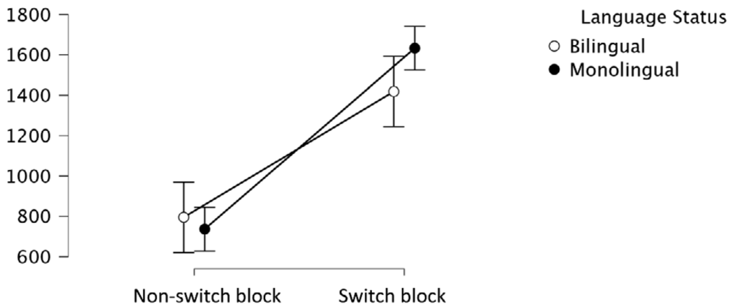

Figure 2. Mean reaction times in milliseconds for bilinguals and monolinguals comparing performance on the nonswitch trials in switch and nonswitch blocks.

subtracted from the reaction times of the nonswitch block trials, and a between-groups *t* test (bilinguals vs. monolinguals) was conducted. Although bilinguals had a numerically smaller GSC (*M* = 390.61 ms, *SE* = 119.01) compared with the monolinguals (*M* = 583.57 ms, *SE* = 70.85), this was not statistically significant $t(76) = 1.48$, $p = .142$.

A Bayesian analysis was also conducted to confirm whether there is any true effect of language status. This was used to compare the fit of the data under the null and alternative hypotheses. The Bayes factor for language status (BF10) was 0.213, indicating much stronger support for the null hypothesis, suggesting a lack of effect for language status alone for overall reaction times. This analysis revealed strong evidence in favor of the model incorporating the interaction between block type and language status (BF10 = $4.814{*}10^9$), suggesting a GSC advantage for bilinguals. A Bayesian analysis of individual performance found no evidence of a GSC (BF10 = 0.615), or LSC (BF10 = 0.397).

As with Wiseheart et al. (2016), local switch costs were calculated based on reaction times for the switch and nonswitch trials in the switching block. A 2 x 2 switch status (nonswitch trials vs. switch trials) by language status (bilinguals vs. monolinguals) ANOVA was conducted, again using reaction times, but specifically within the switch block. A main effect of switch status was observed [$F(1, 76) = 54.66$, $p < .001$, $\eta^2 p = .418$], with longer reaction times for the switch trials. No main effect of language status was found [$F(1,76) = 2.301$, $p = .133$, $\eta^2 p = .029$], nor was there a significant interaction [$F(1,76) = 1.174$, $p = .282$, $\eta^2 p = .015$]. This suggests no difference between monolinguals and bilinguals for their local switch cost (Figure 3).

Again, a further analysis of LSC was found by calculating switch costs individually for each participant. For this analysis, mean reaction times for the switch trials in switch blocks were subtracted from the reaction times of the nonswitch trials in the switch blocks. A between-groups *t* test (bilinguals vs. monolinguals) found that the bilinguals had a numerically smaller LSC (*M* = 232.87 ms, *SE* = 49.05) compared with the monolinguals (*M* = 312.85 ms, *SE* = 50.43). However, this was not statistically significant [$t(76) = 1.084$, $p = 282$].

A Bayesian analysis was again conducted to compare the fit of the data under the null hypothesis and the alternative hypothesis for the LSC. The Bayes factor (BF_{10}) for language status was 0.846, indicating no evidence for language status and LSC. This analysis revealed strong evidence favoring the model, including the interaction between block type and language status (BF10 = $2.08{*}10^8$), indicating a LSC advantage for bilinguals.

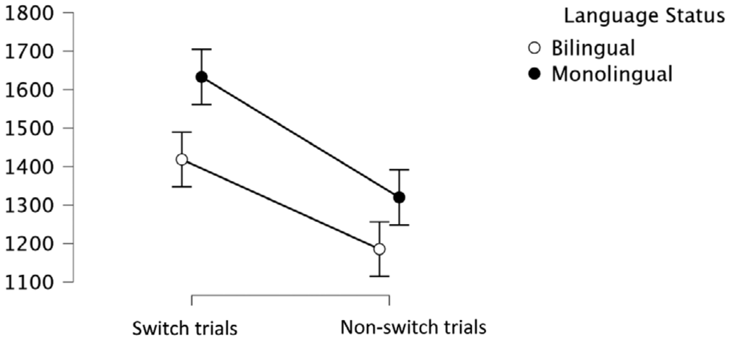

Figure 3. Mean reaction times in milliseconds for bilinguals and monolinguals comparing performance on the nonswitch trials in switch blocks and the switch trials in the switch block.

Table 3. Correlation matrix examining switch frequency with friends, family, and on social media and the relationship with local and global switch costs for the bilingual participants

		GSC	LSC	Family switch	Friends switch	Social media switch
LSC	*r*	.185	–	–	–	–
	p value	.105	–	–	–	–
Family switch	*r*	.181	.019	–	–	–
	p value	.322	.916	–	–	–
Friends switch	*r*	–.004	.202	.167	–	–
	p value	.983	.268	.362	–	–
Social media switch	*r*	–.059	.322	.110	.613	–
	p value	.750	.073	.548	< .001*	–
Total switch	*r*	–.125	–.037	.591	.806	.789
	p value	.274	.748	< .001*	< .001*	< .001*

Note: GSC = global switch cost; LSC = local switch cost.
*Significant effect with $p < .05$.

Finally, as an additional analysis not conducted in the original study by Wiseheart et al., we also examined whether self-reported switching frequency for the bilingual participants was related to the magnitude of global and local switch costs. This analysis comprised a series of correlations, including correlations between the amount of time participants switch languages while conversing with family, friends, or on social media and a total switching estimate and individual LSC and GSC. None of these correlations were significant (Table 3), suggesting that self-perceived switching frequency was unrelated to global or local switch cost. For completeness, a Bayesian correlation was also conducted, which revealed similar findings to the Pearson's correlation in that no evidence was found for a relationship between GSC or LSC and self-reported switch frequency.

Discussion

This study aimed to replicate Wiseheart et al. (2016) by exploring whether language-switching experiences lead to the same bilingual advantage reported for a nonlinguistic task-switching paradigm. Given the discrepancy in the literature surrounding the proposed bilingual advantages in executive functioning that have continued to deepen over the last decade, this replication was undertaken to validate the findings in this area and provide evidence to assist in moving this field of research forward. By replicating the study by Wiseheart et al. and repeating the same analysis used, findings reveal a consistent GSC advantage for the bilingual participants, successfully replicating the findings reported by Wiseheart et al. A medium effect size was found for this GSC advantage in both studies. This suggests a bilingual advantage in domain-general monitoring (Lehtonen et al., 2023) and sustained attentional control (Soveri, Rodriguez-Fornells, & Laine, 2011). This finding is also consistent with other studies in the field, which suggest that highly proficient bilinguals show an advantage over monolinguals because of frequent monitoring, updating, inhibiting, and switching (Lehtonen et al., 2023; Prior & Machinery, 2010).

Additional analyses were conducted for completeness and to reflect more suitable analyses, including a Bayesian analysis. This analysis also showed no general effect of language status, meaning that bilinguals and monolinguals performed comparably on each block individually. When calculating the switch cost, findings again revealed a

GSC advantage for the bilinguals and an LSC advantage compared with the monolinguals. This study, therefore, provides additional evidence to support the notion of a bilingual advantage in task switching, specifically a GSC advantage in young adults. However, further analyses using reaction times to calculate individual switch costs did not yield a significant between-group (bilingual vs. monolingual) effect.

Considering this, the approach to analysis should be carefully considered as different approaches provide conflicting findings. Overall, the evidence from the current study suggests a GSC advantage and possibly an LSC advantage, although null hypothesis significance testing could not detect this finding. As the present study demonstrated, using Bayesian analyses can be beneficial in identifying true results and true null results while also providing information on the magnitude of such effects. The present study demonstrated how it can be valuable to consider multiple analytic approaches to compare results and assess the robustness of the findings. Traditional null hypothesis significance testing used in the original study resulted in the same outcome. In contrast, Bayesian approaches (often considered more suitable for studies with smaller samples and not prone to Type I and II errors) found both LSC and GSC advantages. Bayesian approaches have strengths in calculating the strengths of the evidence rather than using binary cut-off points. They can also confirm hypotheses (Kelter, 2020), making this analysis more robust and appropriate for the present study.

This replication study employed a very similar task-switching paradigm as the original study. Participants recruited for the present study were also of a very similar age, gender, and background to those recruited by Wiseheart et al., although our sample was slightly larger. The primary difference was that our participants completed the task-switching paradigm on their own electronic devices in their setting, as opposed to being in a lab setting. Groups were matched for their nonverbal cognitive intelligence and age; no significant difference was found for general processing speed on the nonswitch blocks. It was impossible to state how participants' L2 proficiency compared with the original study, as Wiseheart et al. did not provide this information. Given the importance of this information (Lehtonen et al., 2023), future studies should ensure that L2 proficiency is reported, as in the present study, to make further conclusions about the role of L2 proficiency.

Interestingly, when using the same task-switching paradigm as Wiseheart et al., we also failed to observe an LSC advantage for the bilinguals when employing significance testing analyses. Similar findings have been reported in the literature using analyses that rely on significance testing (Bialystok & Martin, 2004; Prior & Macwhinney, 2010). Wiseheart and colleagues concluded that LSC is more akin to topic changes within conversations, a switch equally likely to occur for bilinguals and monolinguals. As a result, the strong evidence in favor of a GSC advantage for bilinguals, as reported in the present study aligns with expectations if the language-switching experience is indeed responsible for the observed GSC advantage. Others argue that advantages for LSC may reflect enhanced abilities to regulate interference from the previous task (Wylie & Allport, 2000). Additionally, it might be the case that these GSC advantages are specific to younger bilingual populations, as the present study focused on young adults specifically. This coincides with some studies that report that GSC is highly influenced by age, whereas LSC typically remains stable across the life span (Reimers & Maylor, 2005). On the other hand, additional studies in the field have reported a bilingual advantage for both older adults (Chan, Yow, & Oei, 2020) and children (Bialystok, 2015) in tasks tapping into monitoring and switching skills. To investigate this across different age groups, further research is needed employing Bayesian analyses.

Furthermore, self-reported switching frequency was not related to either LSC or GSC. This finding conflicts with Prior and Gollan (2011) and Verreyt et al. (2016). Although a slight negative correlation was observed for total language-switching frequency and switch costs, as would be expected and reported by Soveri et al. (2011; i.e., as language switching frequency increases, task-switch cost decreases), these correlations were not significant. It is possible that this was due to the self-report nature of calculating language-switching frequency, which may not accurately estimate language-switching frequency among bilinguals with diverse linguistic backgrounds. Alternatively, it is possible that additional factors contribute to switch costs over and above language-switching frequency.

Overall, findings contributed to the argument that bilingualism does indeed confer a bilingual advantage in task switching, as observed in young adult bilinguals with diverse language experiences. This also supports the overlap hypothesis (Paap et al., 2017), suggesting that language switching involves at least some of the same cognitive control mechanisms required for nonlinguistic task switching. There are, however, some important considerations to note. For example, as our participants had a wide range of language backgrounds and experiences, controlling for factors such as socioeconomic status was not possible. Although most participants were full-time students, similar to the original sample recruited by Wiseheart et al., their country of origin and economic background are likely to differ.

Another factor is that the tasks administered to measure executive functioning may have been unreliable due to the task impurity problem. Executive functioning, a multifaceted skill, also operates on additional cognitive processes, meaning these tasks may inadvertently tap into these cognitive processes. This is a known issue for studies relating to executive functioning; however, usually latent variables, such as switch costs, partial out these effects by subtracting performance on switch and nonswitch trials (Friedman & Banich, 2019). Nevertheless, future studies should be mindful of this and carefully consider task design to ensure that the measures used have high reliability in measuring what they set out to assess. This issue could also be reduced by including multiple tasks specifically designed to measure each area of executive functioning to partial out differences in performance, as recommended by Miyake, Emerson, and Friedman (2000).

Further research using similar task-switching paradigms across different ages and populations with large sample sizes is needed. Additionally, a more robust measure of language-switching experiences would be worthwhile in investigating whether the frequency of language-switching is related to task-switching processing speed. Exploring the utility and applicability of such findings across contexts and settings will also be beneficial in determining the magnitude of any such advantages in task switching.

Conclusion

This replication study supported previous findings indicating that some bilingual individuals possess advantages in terms of cognitive flexibility in task switching. These advantages can be attributed to the enhanced cognitive control, inhibitory control, language-switching abilities, and cognitive flexibility bilinguals develop by managing two languages. The enhanced cognitive flexibility observed in the present study is likely due to the ability to alternate between tasks more efficiently but also likely due to the ability to monitor the environment more effectively and inhibit competing information (Haft, Kepinska, Caballero, Carreiras, & Hoeft, 2019; Morales, Yudes, Gómez-Ariza, & Bajo, 2015). In other words, bilingualism appears to enhance general cognitive processes, resulting in benefits for tasks involving cognitive control, particularly those demanding handling conflicting information, such as task switching, as demonstrated here. Caution is needed, however, when considering the transferability to different populations, and consideration is needed regarding the approach to conducting between-group analyses. Further research is necessary to explore the underlying mechanisms of bilingual advantage, such as considering the extent to which the frequency of language switching determines any nonlinguistic task-switching advantages.

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