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Language proficiency, sociolinguistic factors and inhibitory control among bilinguals

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Abstract Bilingualism interacts with cognitive control mechanisms, particularly inhibitory control. It is believed that language proficiency as a measure of the degree of bilingualism may influence inhibitory control. However, this interaction is modulated by sociolinguistic factors associated with bilingual experience. We examined the relationship between language proficiency and inhibitory control and the influence of sociolinguistic factors by comparing high and low proficient Hindi–English bilinguals, and by using a correlational design. A standard go/no-go task with varying proportions of go and no-go trials was used. Study-1 showed that age of acquisition, language use in formal/informal setting, and bilingual switching influenced the interaction between L2 proficiency and inhibitory control. In general, high proficient bilinguals were better at regulating inhibitory control when the demand on inhibition was high compared to that of low proficient bilinguals. Study-2 showed that contextual switching and setting-based use of L2 predicted inhibitory control in a high monitoring condition while use of L1 predicted inhibitory control irrespective of inhibitory demands. However, contextual switching strengthened the interaction between L2 proficiency and inhibitory control whereas use of L1 moderated the relationship between L1 proficiency and inhibitory control. We did not find a significant effect of non-language variables such as fluid intelligence, socioeconomic status, and participation in skilled activities on the relationship between language proficiency and inhibitory control. We emphasize on the role of both L1 and L2 proficiency and the use of a correlational design to investigate the relationship between bilingualism and inhibitory control.

Keywords Bilingualism · Inhibitory control · Domain general cognitive control · L1/L2 proficiency · Language use · Socio-linguistic factors

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Introduction

The cognitive consequences of bilingualism pertaining to enhanced domain general cognitive control are related to multiple factors such as language control, maintaining and shifting between languages, proficiency, contextual use, age of acquisition, and executive functions. Most of the evidence is based on the comparisons of bilinguals and monolinguals on executive function tasks with few studies comparing high and low proficient bilinguals (Singh and Mishra 2012; Singh and Kar 2018), high switchers vs low switchers (Festman et al. 2010), and balanced vs unbalanced bilinguals (Rosselli et al. 2016; Xie 2018). The difference between bilinguals and monolinguals are ascribed majorly by the notion of cross-linguistic

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interference in bilinguals, where they have to deal with two different but related mental lexicons (Michael and Gollan 2005), which would reorganize the linguistic and the cognitive systems (Kroll and Bialystok 2013). This enables bilinguals to practice inhibiting the non-relevant language when they are in dual language context. Green (1998) postulated that the suppression of one language during the co-activation of languages is carried out by a domain-general attentional system, which inhibits the activation of the irrelevant language within the context. This leads to the assumption that bilingualism may influence inhibitory control.

Bilingual inhibitory control advantage (BICA) hypothesis and bilingual executive processing advantage (BEPA) hypothesis argue for a specific inhibitory control advantage versus a global RT advantage (Hilchey and Klein 2011) respectively. BICA is attributed to better conflict resolution in an inhibitory control task whereas BEPA is attributed to monitoring for response conflict. Costa et al. (2008) showed that bilingualism positively affects the alerting and executive control networks to facilitate conflict monitoring and conflict resolution. Using the saccadic countermanding task, Singh and Mishra (2015) showed that high proficient bilinguals (Hindi–English) are better at conflict monitoring than low proficient bilinguals. Studies have shown bilingual advantage on various cognitive control tasks including Simon task (Bialystok et al. 2004; Cox et al. 2016), flanker task (Costa et al. 2009; Engel de Abreu et al. 2012; Luk et al. 2011), attention network task (Costa et al. 2008), go/nogo task (Barac et al. 2016), and Stroop task (Blumenfeld and Marian 2013; Singh and Mishra 2012, 2013). Sullivan et al. (2014) in an ERP study using a go/nogo task found that participants who were trained in a second language for 6 months showed larger P3 amplitude associated with no-go trials, which suggested that training in the second language would affect inhibitory control.

Evidence suggests that bilingual advantage on cognitive control is influenced by task demands (Macnamara and Conway 2014; Qu et al. 2015). Studies have shown that bilinguals perform better when task demands are high (Costa et al. 2009; Jiao et al. 2017; Singh et al. 2019; Yang and Yang 2017). For instance, Jiao et al. (2017) found that bilinguals outperformed monolinguals on a modified flanker task (with no-go trials) but not on the one with less demand on working memory. In the second experiment, they observed that bilinguals outperformed monolinguals on a conditional-go/no-go task, which imposed a higher processing demand for response inhibition. Similarly, Costa et al. (2009) manipulated the number of congruent and incongruent trials in a flanker task to modulate monitoring demands on the task. Low monitoring conditions showed no significant difference between bilinguals and monolinguals whereas high monitoring condition showed an overall RT advantage for bilinguals. These findings suggest that the task demands may show varied effects for the interaction between bilingualism and cognitive control.

Recent literature has reported evidences against bilingual advantage as a function of task-specific effects, sample size, socio-economic status (SES) and other environmental variables while comparing bilinguals and monolinguals (Paap et al. 2015). Paap and Greenberg (2013) conducted an extensive study using tasks pertaining to different components of executive functioning and found that bilinguals do not have any kind of advantage and criticized previous research which showed advantage as having low convergent validity. Contradictory to the claims of Paap et al., Engel de Abreu et al (2012) found bilingual advantage even after having a group with lower SES and concluded that SES and other cultural factors may not influence the interaction between bilingualism and cognitive control. In the Indian context, even after controlling for SES and fluid intelligence, Singh and Mishra (2013) found conflict-monitoring advantage in the oculomotor domain supporting that the second language proficiency influences executive control. Similarly, Singh and Kar (2018) also showed better proactive inhibitory control in high-compared to low-proficiency bilinguals, matched on fluid intelligence and SES. The inconsistency in literature is due to the complexity of bilingualism and more research is required (Bialystok 2016). In addition, most of the work has compared bilinguals with monolinguals whereas the involvement of cognitive control may vary as a function of the degree of bilingualism or different groups of bilinguals themselves may show varied cognitive effects.

Language proficiency is one of the core measures of bilingualism. Most of the evidence has examined second language proficiency and its effect on cognitive control. Khare et al (2013) showed a stronger attentional blink effect suggesting advantage with reactive inhibition with higher L2 proficiency in Hindi–English bilingual adults. Singh and Kar (2018) demonstrated better proactive inhibition on a cued go/no-go task in individuals with high L2 proficiency. Similarly, Iluz-Cohen and Armon-Lotem (2013), demonstrated that both L1 and L2 proficiency was correlated with the performance on a Stroop task in terms of the shift in reaction time distributions on the incongruent trials. A recent study by Dash and Kar (2020) demonstrates that L1 proficiency predicts domain general cognitive control and L2 proficiency predicts bilingual language control through reaction times and N200 amplitudes for the ignored repetition condition in a linguistic and nonlinguistic negative priming task. However, some studies have found that language proficiency does not influence cognitive control. For instance, Verreyt et al. (2016) reported that language switching and not L2 proficiency modulates executive control using a flanker and a Simon task. Similar findings reported by Dong and Xie (2014) using the Wisconsin card sorting task (WCST) and flanker task were attributed to the small difference in the level of proficiency between the two groups of bilinguals. Recently, Xie (2018) reported the effect of L2 proficiency on conflict resolution and not inhibition and set shifting. However, this null effect for inhibition and set shifting needs to be interpreted with caution as it is based on a multifactorial task like WCST.

It is also acknowledged that the way languages are used may also influence cognitive control (Green 2011; Yang et al. 2016). We argue that language use and related factors define bilingual experience, and may influence proficiency and its interaction with cognitive control. Moreover, language proficiency is a dynamic phenomenon and is influenced or shaped by factors such as age of acquisition, frequency of use of languages, setting-based use of languages, language use across different activities, exposure to L1 and L2, and contextual switching between languages. The relationship between such contextual factors and cognitive control is well described by the ecological perspective or the adaptive control hypothesis (Green and Abutalebi 2013), which suggests that cognitive control, is influenced by language experience. Luk and Bialystok (2013) operationalized bilingualism as marked by two key factors, language use and language proficiency based on a factor analysis to account for the heterogeneity observed in the bilingual population. These factors explain the variability in bilingual population related to contextual use and switching between languages, and may contribute to the cognitive outcomes of bilingualism.

Domain general control processes are affected by language experience which is influenced by the language environment (Christoffels et al. 2013). Cognitive control in bilinguals is not only affected by bilingual proficiency but also context-based use of languages (Green and Abutalebi 2013). The dynamics of language use (in the domains of speaking/understanding as well as reading/writing), exposure across settings and activities may influence the bilingual experience. In addition, language proficiency itself is shaped with the frequency of use of a particular language (Dash and Kar 2012). Previous studies have shown a significant correlation between language proficiency and language use (communication) and their relationship with cognitive control (Christoffels et al. 2013; Verhagen et al. 2020). Since language use varies across settings and does not have a similar pattern for L1 and L2, we expected to find variations in the effect of proficiency on cognitive control as a function of setting-based language use, exposure, and age of acquisition.

Language context determines the frequency of use as well the frequency of switching between languages known to a bilingual and is therefore, a primary factor influencing cognitive control (Blanco-Elorrieta and Pylkkänen 2018). Bilinguals in behavioural ecologies may move from single language context to dual language context and vice versa, which may lead to an increased demand for anticipation, goal-maintenance, conflict monitoring, interference suppression and response inhibition. Adaptive control hypothesis (Green and Abutalebi 2013) proposes that, different interactional contexts exert varying language control demands, and herein enforce the need to adapt and control executive functions. A person in a single language context should avoid the intrusion from the non-relevant language at least partially. In the dual language context, the demands on inhibitory control are more as compared to unilingual mode. Dense code switching may probably facilitate co-operation between the activation of the languages rather than competition. Young adults are likely to engage more in dual language contexts, fostering competition between the two languages that would require more resources with respect to cognitive control. Moreover, in the Indian context, more commonly, use of L1 and L2 depends on the settings which create the language context; for instance, L1 is mostly used with family and friends, whereas use of L2 is dominant in formal settings at work and with colleagues resulting in sustained language contexts. The population examined in the current study included only native Hindi (L1) speakers, although being university students, the frequency of use of both Hindi (L1) and English (L2) is likely to be driven by the context. Being sequential bilinguals, the participants acquired the second language with formal schooling. Exposure to second language was also mostly limited to formal settings (i.e., school/college/office). Therefore, the current study investigated the relative contribution of language use and other contextual factors towards language proficiency and the interactive effect of both on inhibitory control.

Two studies were conducted to investigate the relationship between language proficiency and inhibitory control by taking second language proficiency as a categorical variable in the first study and by using a correlational design in the second study. In Study-1, non-language variables (SES, fluid intelligence, working memory, participation in team-sports, and skilled activities) and sociolinguistic factors (language use, exposure, switching behaviour, and age of acquisition of L2) were taken as covariates. In Study-2 these factors were treated as moderators and/or mediators for the relationship between L1/L2 proficiency and inhibitory control. Second language proficiency was taken as a categorical variable in the first study to be consistent with most of the literature on bilingual cognitive advantage comparing monolinguals and bilinguals or high- versus low-proficiency bilinguals. In both the studies, a standard go/no-go task with varying demands on inhibitory control was used. Demands on inhibitory control could be varied by manipulating the proportion of go and no-go trials (20%, 50%, 80% no go trials). The 80-20 condition (20% no-go trials) places greater demand on inhibition making it difficult to withhold the ongoing prepotent response (Bruin and Wijers 2002). Whereas, the 50-50 condition is a high monitoring condition with equal probability for response selection and inhibition on go and no-go trials respectively. ERP studies have shown equally higher N2 amplitudes for both go and no-go trials in case of 50% go/no-go trials (Nieuwenhuis et al. 2003). In the context of bilingualism, Singh and Mishra (2013) used 50-50 proportion as high monitoring condition in an oculomotor Stroop task and found Stroop interference effect only in the 50-50 condition in high proficient bilinguals whereas, Costa et al (2009) found an overall RT advantage on 50-50 and 75-25 conditions in a flanker task among bilinguals compared to monolinguals. Therefore, we used the three proportions of go and no-go trials to vary the demand on inhibitory control. In Study 1, it was hypothesized that high proficient bilinguals would show fewer no-go errors than low proficient bilinguals, especially in the high monitoring condition (50% go/no-go trials) as well as when the demand on inhibitory control was high in the 80-20 proportion condition. Furthermore, sociolinguistic factors would modulate the interaction between second language proficiency and inhibitory control. However, non-language variables were not expected to affect this interaction, given that previous studies demonstrate the effect of proficiency on cognitive control even after controlling for variables such as fluid intelligence and socioeconomic status (Singh and Mishra 2013; Singh and Kar 2018). The second study examined the relationship of L1 and L2 proficiency with inhibitory control moderated by socio-linguistic factors. This was important in view of the previous findings related to the relationship between L1 proficiency to domain general cognitive control and L2 proficiency with bilingual language control (Iluz-Cohen and Armon-Lotem 2013; Dash and Kar 2014, 2020). The overall hypothesis is that proficiency as a measure of degree of bilingualism would influence inhibitory control and would show heterogeneity in terms of how it gets modulated by other factors related to bilingual experience.

Study 1

Introduction

The first study examined the effect of second language proficiency on inhibitory control as modulated by factors (covariates) such as age of acquisition of L2, setting-based use of L1 and L2, exposure to L1/L2, and self-reported bilingual switching. We also examined if the interaction between language proficiency and inhibitory control was influenced by non-language factors such as fluid intelligence, socioeconomic status, working memory, frequency of engagement in team sports and skilled activities. We hypothesized a significant effect of second language proficiency with high proficient bilinguals showing better inhibitory control particularly in conditions with greater task demand, on a go/no-go task with nonlinguistic stimuli. The non-language factors were not expected to influence this interaction. However, the language use related factors were expected to influence the interaction between second language proficiency and inhibitory control.

Methodology

Participants

72 college students from Allahabad in the age range of 18–28 years, whose first language is Hindi (L1) and second language is English (L2) were recruited for the study, out of which 12 participants were screened out of the main experiment due to unmatched language proficiency profiles across screening measures. The remaining 60 participants (32 males and 28 females) were categorized into two groups of 30 participants each based on their L2 proficiency scores (L1 proficiency matched) on different tests as high proficient bilinguals (HPB) and low proficient bilinguals (LPB). The mean age of the participants was 21.62 (± 1.96) years. Written informed consent was obtained from the participants. The study was approved by the Institutional Ethics Review Committee, University of Allahabad.

Proficiency and screening measures

The categorization into the two groups (HPB and LPB) was based on three different measures; picture description, LexTALE and self-rated proficiency (see Table 1). For categorizing into HPB, the participant must have scored 80% or more in picture description task and, should have scored 80% or more in either LexTALE or self-rated speaking and listening proficiency combined. Similarly, for being categorized into LPB, the participant must have scored less than 70% in picture description and, should have scored less than 70% either in LexTALE or in self-rated speaking and listening proficiency combined.

Picture description task was the primary measure and self-rated proficiency and LexTALE were secondary measures for classifying participants as HPB or LPB due to the following reasons: (a) performance on this task is highly correlated with the L1/L2 proficiency across language domains of speaking, understanding, reading and writing; (b) LexTALE is prescribed to be apt for moderate to high proficient L2 (English) speakers (Lemhöfer and Broersma 2012); (c) for some participants, self rated proficiency did not match with the performance on LexTALE.

Picture description task Picture description task was used as an objective measure of spoken language proficiency. In this task participants were shown two pictures one at a time and were instructed to describe one picture in Hindi and the other in English by carefully focusing on the theme of the picture as well as the individual items in that particular picture. A grand rubric score out of 18 was calculated by summing the scores on the following aspects: overall impact and achievement of purpose (whether the participant establishes main idea), organization and techniques (coherence and cohesion with test, method of organization) and mechanics (focusing on grammar, pronunciation, presence of pause) (Dash and Kar 2012).

Participants with a score of 15 (~ 80% of total score) or more in describing a picture in L2 were considered HPB and participants with a score of 12 (~ 70% of total score) or lesser were considered LPB [$t(58) = 23.78$, $p < 0.001$]. The participants were matched on their picture description in L1 [$t(58) = 1.22$, $p = 0.23$].

LexTALE test LexTALE (Lemhöfer and Broersma 2012) is basically a lexical decision task. It was administered to assess language proficiency in L2 (English) for both the groups. LexTALE is a test of vocabulary used to examine proficiency in English language. This test requires the participants to decide if the string of letters presented one at a time is a word or a non-word in English and respond using the mouse click on 'yes' if it is a word or 'no' if it is not a word. The task consists of 63 items out of which 3 items are for practice, 40 words and 20 non-words. We used MATLAB script (https://www.lextale.com) to compute the percentage score, number of correct responses for words and number of correct responses for non-words. The d-prime scores were calculated for accuracy analysis on this task to account for false alarms.

Table 1 Showing the mean comparisons between high- and low- proficiency bilinguals with respect to proficiency and socio-linguistic variables

Language measures	High proficiency bilinguals [mean (SD)]	Low proficiency bilinguals [mean (SD)]	*p* value
Picture description (L1)	16.90 (0.88)	16.63 (0.81)	0.23
Picture description (L2)	16.17 (1.12)	7.37 (1.69)	< 0.001
LexTALE	80.71 (9.70)	60.29 (9.64)	< 0.001
D-prime (LexTALE)	1.95 (0.87)	0.60 (0.61)	< 0.001
Picture naming (L1)	44.57 (0.77)	44.80 (0.41)	0.151
Picture naming (L2)	44.23 (1.52)	40.87 (2.78)	< 0.001
Overall self-rated proficiency (L2)	57.33 (7.21)	39.60 (12.74)	< 0.001
Speaking and listening self-rated proficiency (L1)	18.57 (2.39)	18.40 (1.69)	0.76
Speaking and listening self-rated proficiency (L2)	17.37 (1.88)	11.90 (4.11)	< 0.001
L1 switch	9.17 (1.68)	10.30 (2.07)	0.024
L2 switch	9.50 (1.76)	8.57 (1.57)	0.034
Contextual switch	8.97 (2.80)	9.47 (1.98)	0.43
Unintended switch	7.33 (2.58)	7.20 (2.17)	0.83
Overall language switch	34.97 (6.87)	35.53 (4.69)	0.71
Formal use of L1	38.71 (14.90)	64.23 (18.67)	< 0.001
Informal use of L1	51.58 (13.83)	67.17 (12.58)	< 0.001
Formal use of L2	62.19 (14.99)	35.77 (18.67)	< 0.001
Informal use of L2	49.20 (14.30)	32.90 (12.62)	< 0.001
Exposure duration of L1	60.00 (16.45)	69.27 (19.50)	0.051
Exposure duration of L2	40.83 (18.25)	30.73 (19.50)	0.043
Age of L2 acquisition	4.77 (1.50)	8.17 (7.47)	0.02

Picture naming task One hundred coloured pictures were taken from Snodgrass and Vanderwart database (Snodgrass and Vanderwart 1980). The pictures were rated for familiarity and frequency on a five-point Likert scale in Hindi and English by 20 Hindi–English bilinguals. Ten bilinguals rated the pictures for Hindi while the other 10 rated for English. 90 of those pictures which were rated above 3.5 for both familiarity and frequency on average in both the languages were taken for the study. The 90 pictures were divided randomly into two blocks with 45 pictures in each. Participants were instructed to name one block of pictures in Hindi and the other in English. One point was scored for every correct response.

Language background questionnaire Language background questionnaire was administered individually for each participant in order to collect information about age of acquisition of L2, frequency of language use in different formal and informal settings, task contexts (reading newspaper, social media, communication with family, friends, and colleagues, watching television etc.), exposure to L1 and L2, and self-rated proficiency across language domains for both L1 and L2 in reading, writing, speaking, syntax, and listening. The age of acquisition of L2 was recorded in categories of 0–3 years, 3–6 years, 6–10 years, 10–13 years and 13–16 years. The midpoint of each of the categories were weighted as 1.5, 4.5, 8, 11.5 and 14.5 respectively.

Bilingual switching questionnaire (BSWQ) Bilingual switching questionnaire (Rodriguez-Fornells et al. 2012) was employed to assess the switching behavior (between languages) of participants through self-report. BSWQ is a 5-point Likert scale with 12 statements. There are 4 dimensions for the scale; first-language (L1) switch: the tendency to switch from the second-language (English) to the first-language (Hindi); second-language (L2) switch: the tendency to switch from the first-language (Hindi) to the second-language (English); contextual switch (CS): the tendency to switch between languages in accordance with the situation and environment; and unintentional switch (US): the measure of unawareness regarding the language switch.

Cognitive assessment

Raven's standard progressive matrices (Raven et al. 2000) Raven's SPM is a standard test of fluid intelligence. It is a non-verbal test where the participants are shown a main figure with a missing part in it. The participant has to choose one out of six given options, which suits the best to complete the target figure. There are 60 items divided into 5 sets with 12 items in each set. The difficulty of the task increases as it progresses across items.

Digit span task A digit-span task was used to measure working memory capacity. A set of random number sequences was verbally read out to the participants; each number with a gap of approximately 1 s. The digit forward task required the participant to repeat the digits in a set in the same order as they were presented. The digit backward task required the participants to repeat the digits in a backward sequence i.e., in a reverse order. Number of correctly reported trials comprised the score on this task. The maximum possible score on this task was 26. If the participant responded incorrectly for two successive trials of the series, the task was terminated. The numbers were read out in the participant's language of choice (English/Hindi).

Personal proforma

Personal proforma was used to record self-reported socio-economic status (SES), frequency of playing any team sport, and frequency of engaging in any skilled activity (Table 2).

The go/no-go task

Stimuli and procedure The experiment was designed using the OpenSesame software (Mathôt et al. 2012) version 3.1.6. Stimuli included four white coloured isosceles triangles (pointing up, down, left and right) presented one at a time at the center of the screen against a gray background. The participant was comfortably seated in front of the 19 in. monitor at a distance of 60 cm. A fixation-cross appeared at the center of the screen for a varied duration of 500–1000 ms (steps of 100 ms) followed by the appearance of one of the four triangles (up, down, left or right). The target (triangle) appeared on the screen for 300 ms followed by a blank screen for 700 ms allowing a response window of 1000 ms (see Fig. 1). The participant was instructed to respond by pressing the spacebar as quickly and accurately as possible whenever the triangle was oriented upwards or downwards (go trial) and to refrain from pressing the spacebar whenever the triangle was oriented towards left or right (no-go trial). The orientation of triangles defining the go versus no-go trials was counterbalanced. The fixation cross reappeared immediately after the response was given or once the response window lapsed. The percentage of go and no-go trials was varied across 50-50, 80-20 and 20-80 proportions run in three separate blocks. To familiarize with the task, 20 practice trials were given at the beginning after giving the instructions. The main experiment consisted of a total of 600 trails subdivided into 3 blocks with 200 trials in each block.

Results

Results presented in Table 1 demonstrate that the high and low proficient bilinguals were matched with respect to L1 proficiency (picture description and self-rated proficiency) whereas high proficient bilinguals were more proficient in L2 compared to low proficient bilinguals. Use of L1 was found to be more among low proficient bilinguals and use of L2 was reported to be greater among high proficient bilinguals. Similarly, exposure duration for L1 was matched whereas exposure for L2 was more among high proficient bilinguals. Within group differences in setting-based use of languages indicated that HPBs used more L2 than L1 in formal setting [$t(29) = 4.332$, $p < 0.001$] and both L1 and L2 almost equally in the informal setting [$t(29) = 0.468$, $p = 0.644$]. In the case of LPBs, L1 use was significantly higher in both formal [$t(29) = 4.717$, $p < 0.001$] and informal settings [$t(29) = 7.452$, $p < 0.001$]. Results presented in

Table 2 Showing the mean comparisons between high- and low- proficiency bilinguals with respect to non-language variables

Non-language measures	High proficiency bilinguals [mean (SD)]	Low proficiency bilinguals [mean (SD)]	*p* value
Fluid intelligence	50.43 (5.23)	48.07 (4.27)	0.060
Working memory	18.03 (3.86)	15.00 (2.49)	0.001
Socio-economic status			
Low	12 (40%)	18 (60%)	0.121
Middle	18 (60%)	12 (40%)	
Upper-middle	0	0	
Frequency of playing any team-sport[a]	0.90 (1.03)	1.50 (1.22)	0.086
Frequency of engaging in skilled activities[a]	1.73 (1.51)	1.17 (1.44)	0.002

[a]Responses were taken on a five-point (0–4) scale

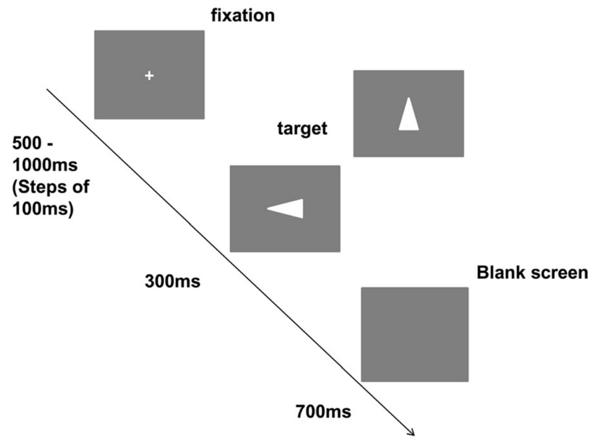

Fig. 1 Trial structure of the go/no-go task

Table 2 show that the two groups were matched on fluid intelligence, socio-economic status and frequency of playing sports.

For the go/no-go task, reaction times and error rates were calculated for the two groups: high proficient bilinguals (HPB) and low proficient bilinguals (LPB) (see Table 3). Outlier RTs were removed based on the mean ± 3SD criteria. On an average, 2% of the trials were removed from the data. The participants had a mean accuracy of 95.44% in the task.

Go-RT analysis

A repeated measures ANOVA with 2 (proficiency: low and high) × 3 (proportions: 50(go)-50(no-go), 80-20 and 20-80) design was performed to compare the Go-RTs as a function of proficiency and proportion of go/no-go trials. Greenhouse–Geisser correction was applied because the sphericity assumption was violated for the main effect of proportion. There was a main effect of proportion [$F(1.74, 101.03) = 82.007$, $p < 0.001$, $\eta_p^2 = 0.586$] for the Go RTs but, there was no main effect of proficiency [$F(1, 58) = 0.565$, $p = 0.455$, $\eta_p^2 = 0.010$]. The results showed faster reaction times for go trials in the 80(go)-20(no-go) compared to 50-50 and 20-80 proportions [$t(59) = 12.583$, $p < 0.001$]; [$t(59) = 10.482$, $p < 0.001$] respectively. The mean difference of the go trials between 50-50 and 20-80 proportions did not attain statistical significance [$t(59) = 1.776$, $p = 0.082$]. The interaction between proficiency and proportion was not significant [$F(2, 116) = 1.898$, $p = 0.160$, $\eta_p^2 = 0.032$].

No-go-error analysis

Given that the aim of the study is to examine inhibitory control among bilinguals, the analysis focused on the comparison of no-go errors across different

Table 3 Mean reaction times (in milliseconds) and error rates (in percentage) of the high-proficiency and low-proficiency bilinguals on the go/no-go task

Measures	HPB [mean (SD)]	LPB [mean (SD)]
Go-RT [50% (go)-50% (nogo)]	445.83 (47.05)	438.94 (51.75)
Go-RT (80-20)	407.57 (41.13)	390.19 (42.27)
Go-RT (20-80)	450.86 (44.62)	450.20 (53.89)
No-go error [50% (go)-50% (nogo)]	5.17 (3.68)	7.40 (4.28)
No-go error (80-20)	23.00 (12.34)	31.33 (13.16)
No-go error (20-80)	1.42 (1.27)	2.19 (2.06)
Go error [50% (go)-50% (nogo)]	1.17 (2.97)	2.17 (3.68)
Go error (80-20)	3.17 (4.55)	3.94 (3.48)
Go error (20-80)	2.08 (5.46)	1.92 (2.76)

proportions between the two groups (see Fig. 2). Repeated measures mixed ANOVA with 2 (proficiency) × 3 (proportion) design, was performed. Greenhouse–Geisser correction was applied because the sphericity assumption was violated for proportion. The main effects of proficiency [$F(1, 58) = 6.935$, $p = 0.010$, $\eta_p^2 = 0.107$] and proportion [$F(1.11, 64.25) = 247.400$, $p < 0.001$, $\eta_p^2 = 0.810$] were significant. Overall LPB showed higher error rates on no-go trials compared to HPB. As expected, overall error rates on no-go trials were higher for the 80-20 proportion compared to 50-50 proportion with least amount of errors for the 20-80 proportion. The interaction between proficiency and proportion was also significant, [$F(2, 116) = 5.429$, $p = 0.020$, $\eta_p^2 = 0.086$].

The post-hoc analysis was performed using Tukey's post-hoc test. No-go errors in the 80-20 proportion were significantly higher for LPB than HPB [$t(58) = 6.846, p < 0.001$], whereas there was no difference between the groups for the 50-50 and 20-80 proportions. Within group difference between 80-20 proportion and 50-50 proportion was found in HPBs and LPBs [$t(29) = 14.652$, $p < 0.001$]; [$t(29) = 19.664$, $p < 0.001$] respectively with higher error rates for the 80-20 proportion compared to the 50-50 proportion. Similarly, within group difference between 80-20 proportion and 20-80 proportion was also found in HPBs and LPBs [$t(29) = 17.733$, $p < 0.001$]; [$t(29) = 23.945$, $p < 0.001$] respectively with higher error rates for the 80-20 proportion. However, there was a significant difference between 20-80 and 50-50 proportions in LPBs [$t(29) = 4.281$, $p = 0.035$] but not in HPBs [$t(29) = 3.081$, $p = 0.255$]. LPB showed higher error rates on no-go trials for the 50-50 proportion compared to the 20-80 proportion.

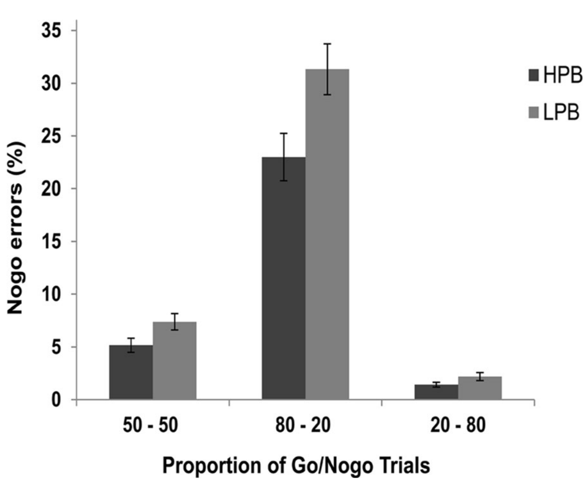

Fig. 2 Mean comparisons of No-go error rates (%) across the three proportions of go/no-go trials among high-proficiency and low-proficiency bilinguals

Covariate analysis

Covariate analysis was performed to test the second hypothesis related to the role of sociolinguistic and non-language variables on inhibitory control (no-go errors) as a function of proficiency among bilinguals (see Tables 4, 5). The analysis was performed using repeated measures ANOVA with 2 (proficiency) × 3 (proportion) design and by adding one covariate at a time for the analysis with error rates on no-go trials across the three proportions as the dependent variable. Greenhouse–Geisser correction was applied because the sphericity assumption was violated for proportion.

Covariate analysis for non-language variables Table 4 presents the results of covariate analysis with non-language variables. The non-language variables including fluid intelligence, working memory, socio-economic status, frequency of playing any team sport and practicing any skilled activity neither influenced the main effect of proficiency and proportion of go/no-go trials nor the interaction between proficiency and inhibitory control (no-go errors). Fluid intelligence only affected the main effect of proportion on the go/no-go task but it did not influence its interaction with proficiency.

Covariate analysis for socio-linguistic and other language variables Table 5 presents the results of the covariate analysis with sociolinguistic factors and other language variables. Frequency of language switching was examined using a self-report measure. When L1 switch (tendency to switch to L1) was taken as a covariate, the effect of proficiency and proportion was sustained. However, L1 switch showed a tendency towards diluting the interaction between proficiency and proportion of go/no-go trials. L2 switch, unintended switch, contextual switch or overall switching tendencies did not affect the main effect of proficiency or the interaction between proficiency and proportion of no-go errors. Main effect of proportion was affected when L2 switch, contextual switch and overall switch were added as covariates.

Language use in the formal and informal settings was examined through the language background questionnaire. When the use of L1 in formal setting was taken as a covariate, the main effect of proportion was sustained but, the main effect of proficiency and the interaction effect between proficiency and proportion of go/no-go trials were not significant. However, L1 use in informal settings diluted the interaction between proficiency and proportion of go/no-go trials. Use of L2 in formal settings as a covariate, diluted the

Table 4 Comparing the performance of the high and low proficient bilinguals on the go/no-go task (proficiency × proportion of go/no-go trials) with non-language variables as covariates

Covariate	Main effect/interaction effect	F value	*p* value	Partial eta square value
Fluid intelligence	Proportion	2.319	0.130	0.039
	Proficiency	6.237	0.015	0.099
	Proficiency × proportion	4.973	0.026	0.080
Working memory	Proportion	6.474	0.011	0.102
	Proficiency	7.715	0.007	0.119
	Proficiency × proportion	5.191	0.023	0.083
Socio-economic status	Proportion	33.773	< 0.001	0.372
	Proficiency	6.085	0.017	0.096
	Proficiency × proportion	4.420	0.036	0.072
Frequency of playing any team-sport	Proportion	160.758	< 0.001	0.738
	Proficiency	10.254	0.002	0.152
	Proficiency × Proportion	8.434	0.004	0.129
Frequency of practicing any skilled activity	Proportion	115.452	< 0.001	0.669
	Proficiency	6.986	0.011	0.109
	Proficiency × proportion	5.525	0.019	0.088

Table 5 Comparing the performance of the high and low proficient bilinguals on the go/no-go task (proficiency × proportion of go/no-go trials) with sociolinguistic and other language variables as covariates

Covariate	Main effect/interaction effect	F value	*p* value	Partial eta square value
L1 switch	Proportion	4.503	0.034	0.073
	Proficiency	5.559	0.022	0.089
	Proficiency × proportion	3.920	0.048	0.064
L2 switch	Proportion	1.730	0.194	0.029
	Proficiency	9.522	0.003	0.143
	Proficiency × proportion	7.304	0.007	0.114
Contextual switching	Proportion	3.616	0.057	0.060
	Proficiency	6.145	0.016	0.097
	Proficiency × proportion	4.687	0.030	0.076
Unintended switching	Proportion	19.684	< 0.001	0.257
	Proficiency	6.768	0.012	0.106
	Proficiency × proportion	5.394	0.020	0.086
Overall switching	Proportion	0.698	0.500	0.012
	Proficiency	6.667	0.012	0.105
	Proficiency × proportion	5.219	0.022	0.084
Formal use of L1	Proportion	17.775	< 0.001	0.238
	Proficiency	3.585	0.063	0.059
	Proficiency × proportion	2.136	0.147	0.036
Informal use of L1	Proportion	10.471	0.001	0.155
	Proficiency	4.773	0.033	0.077
	Proficiency × proportion	3.724	0.054	0.061
Formal use of L2	Proportion	32.901	< 0.001	0.366
	Proficiency	3.303	0.074	0.055
	Proficiency × proportion	1.853	0.178	0.031
Informal use of L2	Proportion	25.766	< 0.001	0.311
	Proficiency	4.303	0.043	0.070
	Proficiency × proportion	3.302	0.070	0.055
Exposure duration of L1	Proportion	9.638	0.002	0.145
	Proficiency	4.799	0.033	0.078
	Proficiency × proportion	3.916	0.048	0.064
Exposure duration of L2	Proportion	69.096	< 0.001	0.548
	Proficiency	4.057	0.049	0.066
	Proficiency × proportion	3.217	0.073	0.053
AoA of L2	Proportion	84.784	< 0.001	0.598
	Proficiency	4.814	0.032	0.078
	Proficiency × proportion	3.686	0.055	0.061

main effect of proficiency as well as the interaction between proficiency and proportion of go/no-go trials. Use of L2 in informal settings affected the interaction between proficiency and proportion of go/no-go trials.

When exposure duration of L1 and L2 were added as covariates, the main effects of both proportion and proficiency were sustained while, the main effect of proficiency was marginally significant when exposure duration of L2 was added as a covariate. However, exposure duration for L2 affected the interaction between proficiency and proportion of no-go error trials while, exposure duration for L1 also reduced the strength of the interaction with a marginally significant effect. The interaction effect between proficiency and proportion of go/no-go trials was affected by age of acquisition of L2, while the main effects were preserved.

To summarize, the covariate analysis showed that language use across formal and informal settings, exposure duration for L1 and L2, age of acquisition of L2 and language switching from L2 to L1 influence the interaction between language proficiency and inhibitory control. Non-language variables such as fluid intelligence, SES, working memory, and participation in team-sports and skilled activities did not influence the interaction between proficiency and inhibitory control.

Discussion

The current study examined the effect of second language proficiency on inhibitory control using a go/no-go task with varying demands on inhibitory control. The effect of socio-linguistic and non-language variables that might influence the interaction between second language proficiency and inhibitory control was also examined. Results showed no significant difference between go-RTs of HPBs and LPBs. The error rates on no-go trials were less for HPB than LPB supporting the bilingual inhibitory control advantage hypothesis. It is important to note that the advantage was found in the 80-20 proportion, in which the no-go trials are much less (20%) and thus require up-regulation of control mechanisms to inhibit the automatic response. Sullivan et al (2014) using go/no-go task (80-20 proportion) found electrophysiological evidence for bilingual advantage in inhibitory control, though the behavioural data of the same did not show any significant difference. This might be due to the brief duration of exposure to the second language, given that the bilingual participants used in the study were given only 6 months training in the second language and/or due to the kind of stimuli used in the study. Our findings are consistent with those studies (Costa et al. 2009; Jiao et al. 2017; Singh and Mishra 2013; Singh et al. 2019; Yang and Yang 2017) where the bilingual advantage was reported only in conditions with higher task demands. We also found higher error rates on no-go trials for the high monitoring condition with 50-50 proportion compared to 20-80 proportion of go/no-go trials in case of LPBs whereas, the same was not observed for HPBs. This suggests that bilingual advantage in inhibitory control may not surface in a less demanding condition. Hilchey and Klein (2011) argue that lesser trials are likely to bring an effect in favour of the bilingual advantage and with practice, the effect simply disappears. Costa et al. (2009) found that the significant difference in conflict effect on the 75% congruent (high demanding) condition on the flanker task was present only in the first block but not in the second and third blocks. This cannot be the case with the current findings as there were enough trials and the significant difference in the inhibition effect between HPB and LPB was observed in the second block. By the second block the participant would have already completed an extensive session of the task with a different task demand (80% or 20% no go trials).

The results of the covariate analysis imply that the non-language variables such as socio-economic status, fluid intelligence, working memory, and frequency of playing a team sport and practicing any skilled activity did not modulate the effect of second language proficiency on inhibitory control. However, variables related to language use, exposure, and switching between languages influenced the interaction between proficiency and inhibitory control by reducing the effect size. L2 to L1 switch (trend effect), use of L2 (English) and L1 (Hindi) in formal and informal settings was found to modulate the effect of second language proficiency on inhibitory control. The adaptive control hypothesis and its behavioural ecology account (Green and Abutalebi 2013) suggests that people tend to use language disproportionately in different contexts, which may affect the role of language proficiency towards the up-regulation of cognitive control. Interestingly, setting-based use of L1 also influenced the interaction between second language proficiency and inhibitory control. This finding suggests that greater use of L1 may result in greater competition/intrusion for L2 in terms of use and maintenance of L2 resulting in the need for greater inhibitory control. During language use, both languages are active and bilinguals need to allocate attention to the two language systems (at times conflicting) (Green 1998). The effect of proficiency was altered only by formal use of L1 and L2. This could be because high-proficiency bilinguals show larger differences in the use of L1 and L2 based on settings and low-proficiency bilinguals show negligible effect of settings on language use. Overall, high-proficiency bilinguals reported greater use of L2 in the formal setting while using both L1 and L2 at comparable levels in the informal setting, and low proficient bilinguals reported greater use of L1 in both formal and informal settings (see Table 1). Exposure duration of L1 (trend effect) and L2, age of acquisition of L2 also altered the interaction between L2 proficiency and inhibitory control. Exposure duration to L2 altered the interaction more than did exposure duration to L1. This implies that exposure to L2 is important for achieving proficiency in L2 as well as to attain better inhibitory control. Similarly, age of acquisition of L2 early in life leads to better proficiency in L2 thereby affecting inhibitory control.

Representations and meanings of L1 are connected weakly to L2 but are stronger from L2 to L1 (Green 1998). Exposure duration to L2, use of L2 in formal and informal settings are significantly greater for HPBs than LPBs, thereby demanding more inhibitory resources when a person is in L2 mode. Frequency of switching from L2 to L1 also influenced the interaction between L2 proficiency and inhibitory control. Given that associations are relatively stronger from L2 to L1 (Green 1998) and based on experimental evidence on asymmetrical switch cost (Christoffels et al. 2007), it can be inferred that more effort is required when a person switches from L2 to L1 than vice versa because the inhibition on L1 (relatively larger) needs to be released for reactivation (Kroll et al. 2006).

To summarize, Study-1 found inhibitory control advantage for high proficient bilinguals using a go/no-go task in conditions demanding greater inhibitory control and that socio-linguistic variables but not non-language variables modulate the effect of proficiency as a measure of degree of bilingualism on inhibitory control.

Study 2

Introduction

Defining bilingualism as a categorical variable makes studies on bilingualism difficult to an extent (Luk and Bialystok 2013) since bilingualism is a dynamic multidimensional construct. Between-subject comparisons have shown significant effects of bilingualism on cognitive control however it is not sensitive to the variations within the group of bilinguals or high versus low proficiency bilinguals. Therefore, treating bilingualism as a continuous variable can give better or different outcomes by looking at the degree of bilingualism (Bialystok and Barac 2012). The second study intended to validate the findings of the first study by using a correlational design.

Recent studies have examined bilingualism as a continuous variable by taking a large heterogeneous bilingual population (Luk and Bialystok 2013). Factors such as self-reported language proficiency, language use, and exposure to languages known, may vary among bilinguals as a function of their long-term bilingual experience (Fishman and Cooper 1969; Luk et al. 2011; Bialystok and Barac 2012). In Indian context, the variation in language use, language organization and interdependence of both languages observed in bilinguals is not very clear. The validation study (Dash and Kar 2012) for a comprehensive test of language proficiency in Hindi (L1) and English (L2) considered all the factors including self rated proficiency, language use, language exposure, age of acquisition, and objective measures of proficiency across the domains of speaking, understanding, reading and writing. Factor analysis showed a different pattern of language organization for L1 and L2 with greater clustering of tasks across domains for L2 compared to L1 emphasizing the need to look at proficiency in both languages and its influence on cognitive control. Most of the work in Indian context has examined the relationship between second language proficiency on cognitive control (Khare et al. 2013; Singh and Mishra 2012; Singh and Kar 2018).

Proficiency as a continuous variable also helps in eliminating the methodological bias. Moreover, correlational design allows examining the relationship between both L1 and L2 proficiency separately and how each is correlated with cognitive control. Setting-based use of L1 and L2 leads to varying demands on cognitive control including anticipation, goal-maintenance, conflict monitoring, and inhibition. Therefore, Study 2 was conducted with a larger sample to account for the relationship between L1 as well as L2 proficiency and how each predicts control mechanisms moderated by sociolinguistic variables. This is particularly relevant in Indian context (where we mostly find dual language context rather than single language context), given the findings, which suggest that better cognitive control is related to dual language contexts (Crespo et al. 2019; Wu and Thierry 2013). It was hypothesized that both L1 and L2 proficiency would predict inhibitory control and this interaction will be moderated by setting-based language use, language exposure, age of acquisition and bilingual switching. Given the relationship between proficiency as a measure of bilingualism and inhibitory control when the task demand is high, we hypothesized that contextual switching would be a significant predictor for inhibitory control.

Method

Participants

Hundred one-student volunteers (57 Males and 44 Females) from University of Allahabad participated in the study. Inclusion criteria applied for the selection of participants was based on age and language. Bilingual students (Hindi as L1 and English as L2) in the age range of 18–30 years (mean age: 21.59 ± 2.72 years) participated in the study. Informed consent was obtained from each participant. Personal proforma was used to collect information about age, education, socio-economic status (SES), and history of any psychiatric/neurological disorders.

The study was conducted in CBCS, University of Allahabad and approval was obtained from the Institutional Ethics Review Committee, University of Allahabad.

Measures

Language proficiency related measures Language background questionnaire, self-switching questionnaire and objective measures such as picture naming, picture description, listening comprehension and LexTALE (English only) were used to examine language proficiency in L1 and L2 (Table I in Appendix). Except listening comprehension all the other measures were the same as in Study 1, therefore the description of these measures is not repeated here.

Listening comprehension task Listening comprehension task was added to the measures of language proficiency and was administered to assess auditory comprehension in L1 and L2. One passage was read out loud by the experimenter and the participant had to listen to the passage carefully and at the end of the passage 5 questions were asked from the passage. Correct answer for each question carried one point. Two different passages, matched in length and difficulty level in terms of content, were used and correct response to each question carried one point. The participant could score a maximum of five points for each language.

Cognitive assessment

Wechsler's abbreviated scale of intelligence Wechsler's abbreviated scale of intelligence (WASI-II) is a test for general intelligence for ages 6–89 years. It is a battery of four subtests: vocabulary (31-item), block design (13-item), similarities (24-item) and matrix reasoning (30-item). The matrix reasoning test was used for the current study as a measure of fluid intelligence in order to reduce the time taken to administer the complete test.

The go/no-go task

This experiment based on the go/no-go paradigm was designed to examine the relationship between L1–L2 proficiency and inhibitory control.

Predictions

1. L1–L2 proficiency would be negatively correlated with no-go errors. L1 proficiency would emerge as a stronger predictor for inhibitory control compared to L2 proficiency, given the stronger representation of L1.
2. Setting-based language use would moderate the relationship between proficiency and inhibitory control (no-go errors).
3. Non-language variables like SES, working memory and intelligence would not influence the relationship between proficiency and inhibitory control.

Stimuli and procedure The experiment was designed using the OpenSesame software version 3.1.6 (Mathôt et al. 2012). Go/no-go paradigm was used in this experiment to measure inhibitory control. Procedure of the task (trial structure and mode of response) remained the same as described in Study 1. Stimuli used in Study 1 (isosceles triangles) were replaced with "arrow" pointing to right, left, up or down embedded in a white outlined circle presented randomly (see Fig. 3). The direction of arrows representing go versus no-go trials was counterbalanced across participants to avoid bias for certain directions. The proportion of the go and no-go trials was varied in 3 separate blocks of 200 trials each (80-20, 50-50, 20-80 proportions) and the three blocks were presented in a randomized order across participants.

Results

Data obtained was analyzed in terms of reaction times and error rates as a function of proportion of go/no-go trials and trial type (go vs no go) (see Table 6). Outlier reaction times (RTs) were removed based on the mean $\pm$ 3 SD criteria for the condition specific means. On an average 1.31% trials were removed from the data. ANOVA was performed to compare the mean RTs and error rates across the three proportions of go/no-go trials. Regression analysis was performed to examine the relationship between L1 and L2 proficiency and performance on the go/no-go task. Further, Moderation analysis was performed to find out if sociolinguistic variables such as settings based use of language or language exposure variables would moderate the relationship between language proficiency and inhibitory control.

Go RT analysis

One-way ANOVA was performed to find out the effect of proportion [3 (proportions: 50(go)-50 (no-go), 80-20 and 20-80)] on go-trial RTs. Mauchly's test of Sphericity indicated that the Sphericity assumption was violated for proportion. Therefore, Greenhouse–Geisser correction was applied. There was a main effect of proportion [$F(1.57, 151.58) = 48.974$, $p < 0.001$, $\eta_p^2 = 0.329$] for the Go RTs. The post-hoc analysis using Tukey's HSD indicated that the mean go RT for 50-50proportion (M = 422.404 ms, SD = 6.019) was slower than that for the 80-20 proportion (M = 392.385 ms, SD = 7.907) [$p < 0.001$]. Similarly, the mean go RTs for the 50-50 proportion (M = 422.404 ms, SD = 6.019) was significantly faster from that for the 20-80 proportion (M = 444.277 ms, SD = 6.905) [$p < 0.001$]. The mean go RTs for the 80-20 proportion (M = 392.385 ms, SD = 7.907) were significantly faster from the 20-80 proportion (M = 444.277 ms, SD = 6.905) [$p < 0.001$].

Error rates (%) analysis

In order to analyze the effect of proportion manipulation on error rates on go and no-go trials, repeated measures ANOVA was performed with [2 (trial type: go vs no-go trials) $\times$ 3 (proportion: 50-50, 80-20, 20-80) design. Greenhouse–Geisser correction was applied because the Sphericity assumption was violated for the main effect of proportion and the interaction between trial type and proportion. Main effect of proportion [$F(1.46, 145.66) = 333.671$,

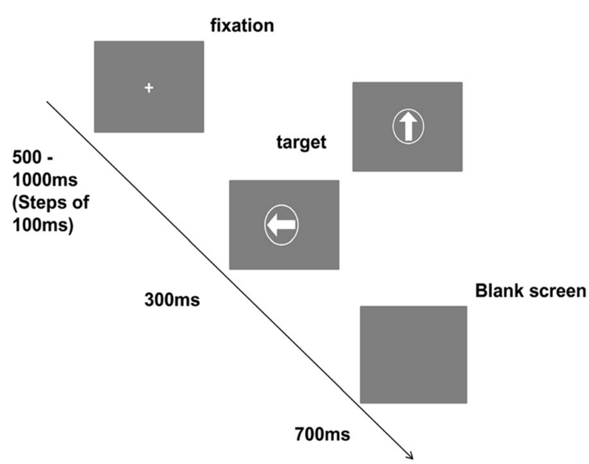

Fig. 3 Trial structure of the go/no-go task for Study 2

Table 6 Reaction times (milliseconds) and error rates (%) on the Go/no-go task

	50-50 proportion	80-20 proportion	20-80 proportion
Go RT mean (SD)	422.404 (6.019)	392.385 (7.907)	444.277 (6.905)
No-go error mean (SD)	9.604 (7.137)	28.540 (14.660)	2.455 (2.241)
Go- error mean (SD)	2.663 (3.320)	6.854 (5.507)	3.341 (4.875)

$p < 0.001$, $\eta_p^2 = 0.769$] and trial type [$F(1, 100) = 146.507$, $p < 0.001$, $\eta_p^2 = 0.594$] was significant. The error rates for no-go trials were more than the go trials. Overall errors were more for the 80-20 proportion compared to the 50-50 and 20-80 proportions (see Fig. 4). There was a two-way interaction between trial type and proportion [$F(1.34, 133.90) = 183.611$, $p < 0.001$, $\eta_p^2 = 0.647$].

The post-hoc analysis was performed using the Tukey's post-hoc test. Results indicated that the mean no-go error rates for the 50-50 proportion (M = 9.604, SD = 7.137) were significantly less than the mean no-go error rates for the 80-20 proportion (M = 28.540, SD = 14.659) [$t(100) = 18.840$, $p < 0.001$]. The mean no-go error rates for the 50-50 proportion (M = 9.604, SD = 7.137) were more than those for the 20-80 proportion (M = 2.455, SD = 2.241) [$t(100) = 7.113$, $p < 0.001$]. The mean no-go error rates for the 80-20 proportion (M = 28.540, SD = 14.659) were more than that for the 20-80 proportion (M = 2.455, SD = 2.241) [$t(100) = 25.953$, $p < 0.001$]. The mean go error rates for the 50-50 proportion (M = 2.663, SD = 3.320) were less than those for the 80-20 proportion (M = 6.854, SD = 5.507) [$t(100) = 4.170$, $p = 0.045$]. The go error rates for 80-20 and 20-80 as well as 50-50 and 20-80 proportions were comparable.

Regression analysis

Stepwise regression analysis was performed with proficiency, sociolinguistic, bilingual switching and non-language variables as predictors and go RTs and no-go error rates as dependent measures. The stepwise regression model allows managing large amounts of potential predictor variables and fine-tuning of the model to choose the best predictor variables from the available options (see Tables 7, 8).

Results indicate that L2 proficiency and contextual switching significantly predicted inhibitory control in a high monitoring condition (50-50 proportion), whereas L1 proficiency predicted inhibitory control in case of both lower and higher demands on inhibitory control (20-80 and 80-20 proportions respectively). L2 use predicted inhibitory control in the 80-20 proportion condition whereas L1 use predicted inhibitory control in the 20-80 proportion condition. Among the language and proficiency variables only contextual switching predicted the go RTs (a measure of goal directed behavior) in a high monitoring condition.

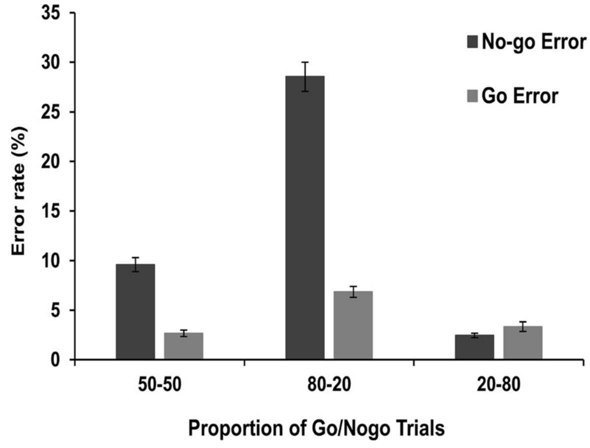

Fig. 4 Error rates (no-go and go errors) across the three proportions of go/no-go trials

Table 7 Relationship between L1 and L2 proficiency, sociolinguistic factors and No-go error rates across the three proportions

Model	Predictor variable	Dependent measures	R^2 value	*p* value
1	L2 proficiency	No go error 50-50	− 0.292	0.002
	Contextual switching	No go error 50-50	0.230	0.016
2	L1 proficiency	No go error 80-20	− 0.354	0.001
	L2 informal use	No go error 80-20	0.262	0.010
3	L1 proficiency	No go error 20-80	− 0.419	0.000
	L1 informal use	No go error 20-80	0.253	0.011

Table 8 Relationship between sociolinguistics variables, non-language variables and reaction times on Go trials across the three proportions

Model	Predictor	Dependent measure	R^2 value	*p* value
1	Contextual switching	Go RT 50-50	− 0.221	0.026
2	WM (DS backward)	Go RT 80-20	0.318	0.015
	WM (DS-forward)		− 0.243	0.032
3	SES	Go RT 20-80	0.200	0.045

WM working memory, *DS* digit span, *SES* socioeconomic status, *go-RT* go-reaction times

Working memory span predicted go-RTs in the 80-20 proportion condition, whereas the relationship between SES and go-RTs was not significant. L1/L2 proficiency and Non-language variables such as intelligence, participation in team sports and skilled activities were not correlated with Go-RTs or no-go errors.

Moderation/mediation analysis

Regression analysis was followed by moderation analysis, which provides an overall context to understand the interaction dynamics of the given variables. The predictors (sociolinguistic and nonlanguage variables) obtained from the stepwise regression analysis were further subjected to moderation analysis with Language proficiency as the predictor variable, L1 and L2 use in formal/informal settings, and contextual switching as moderator variables and performance on go/no-go trials (go RTs and no-go error rates) as dependent variables were entered in the analysis. Moderation/mediation analysis was not performed with non-language variables as moderators since none of these variables emerged as significant predictors of performance on the go/no-go task in the regression analysis except working memory which predicted go RTs with 80% go trials, a condition with low task demand with respect to inhibitory control.

Moderation implies an interaction effect, where introducing a moderating variable changes the direction or magnitude of the relationship between the independent and dependent variable. Moderation analysis was performed in SPSS version 20. Outliers were calculated and removed using Mahalanobis, Leverage and Cook's distance methods. The independent variables and the moderator variable in every model were centered prior to entering them into the model. Two models showed significant moderation out of the three models that were attempted based on the results of the regression analysis (see Figs. 5a, b, 6a, b). Mediation analysis was also performed for the same variables used for the moderation analysis and one out of three models showed significant yet partial mediation. Given the number of factors entered in the analysis was more the moderation/mediation analysis may require a much larger sample which could have been one of the reasons that not all models showed a significant moderation effect.

Model 1 In the first moderation model L2 self-rated proficiency was taken as the independent variable, contextual switching (CS) as the moderator and no-go errors (50-50 proportion) as the dependent variable (see Fig. 5a, b). Moderation analysis was conducted to illustrate whether CS would moderate the relationship between L2 proficiency and inhibitory control (no go

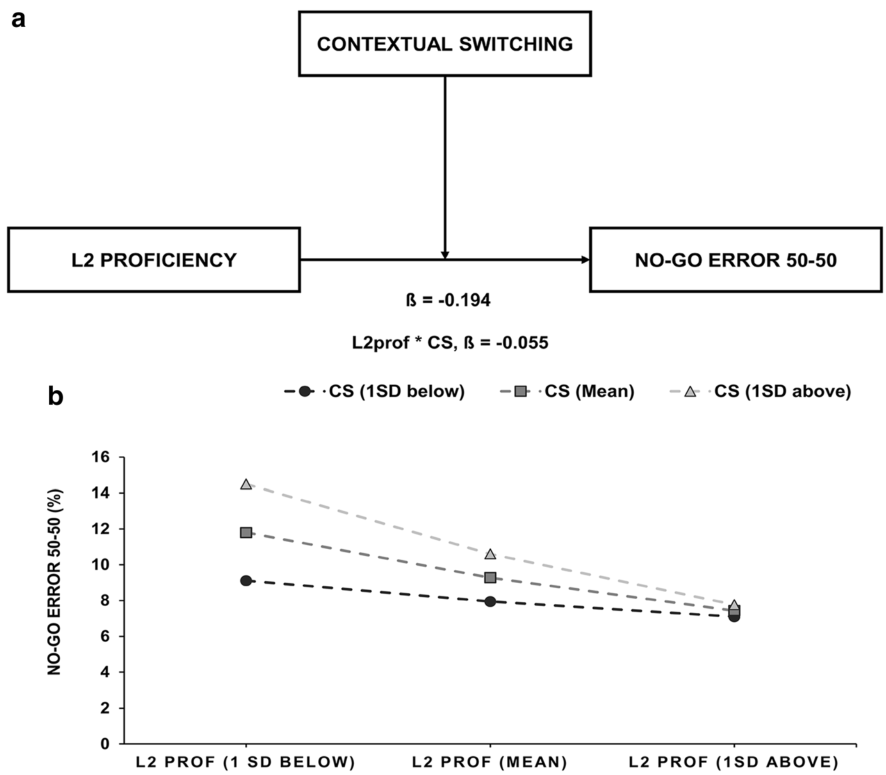

Fig. 5 **a** Moderation model depicting the regression coefficients for the relationship between with L2 proficiency and inhibitory control (no-go error rates: 50-50 proportion condition) as moderated by contextual switching. **b** Interaction plot depicting simple slopes of L2 proficiency predicting inhibitory control (no-go error rates) for 1 SD below the mean of contextual switching (CS), mean of CS and mean 1 SD above the mean of CS

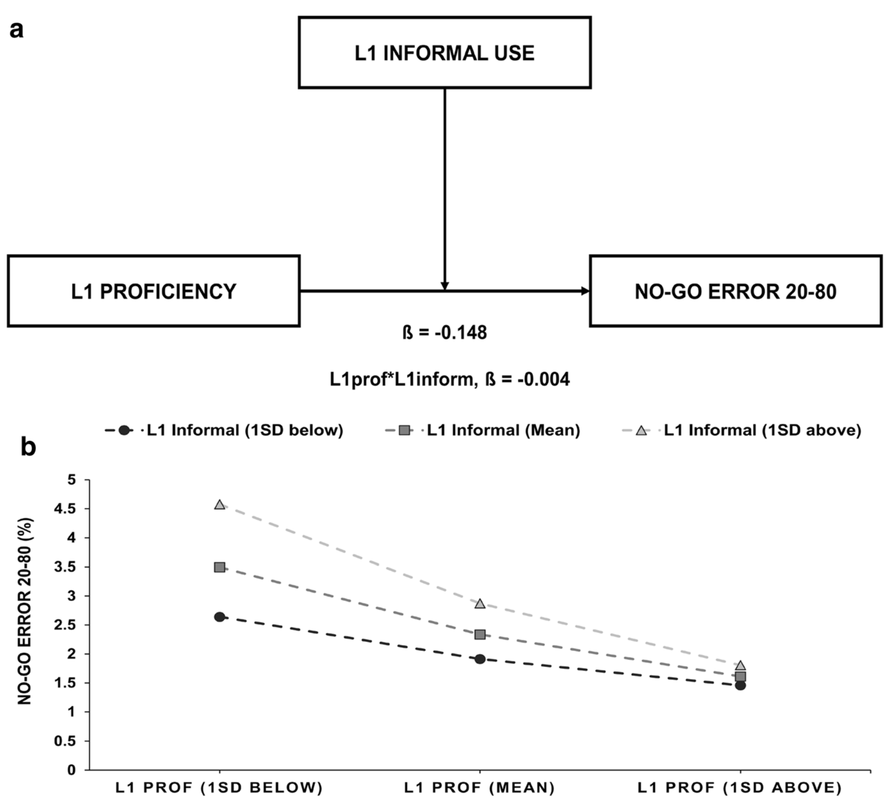

Fig. 6 **a** Moderation model depicting the regression coefficients for the relationship between L1 proficiency and inhibitory control (no-go error rates: 20-80 proportion condition) as moderated by L1 use in informal settings. **b** Interaction plot depicting the simple slopes of L1 proficiency predicting inhibitory control (no-go error rates: 20-80 proportion) for 1 SD below the mean of L1 use in informal settings, mean of L1 use in informal settings and 1 SD above the mean of L1 use in informal settings

errors in a high monitoring condition). In the first step L2 proficiency and CS were included in the model. These variables accounted for a significant amount of variance in the data, $R^2 = 0.149$, $F(2,98) = 8.560$, $p < 0.001$. Further the interaction term was added to the model. This interaction accounts for a less significant amount of variance in no-go error (50-50 proportion). R^2 *change* = 0.044, *F change* (1, 97) = 5.318, $\beta = -0.055$, $t(97) = -2.306$, $p = 0.023$. Examination of the interaction showed that with higher L2 proficiency and CS, no-go error (50-50) decreases. High L2 proficiency was associated with comparable no go errors in case of low, average or high CS. However, at low L2 proficiency with higher rate of CS, highest error rates on no-go trials were observed. However, CS moderated the relationship between L2 proficiency and inhibition in a high monitoring condition.

Model 2 In the second moderation model self-rated L1 proficiency was taken as the independent variable, L1 use in informal setting as the moderator variable and no-go error rates (20-80 proportion) as the dependent variable (see Fig. 6a, b). Moderation analysis was conducted to illustrate whether L1 use in informal setting would moderate the relationship between L1 proficiency and inhibition (error rates on no-go trials: 20-80 proportion). In the first step L1 proficiency and L1 use in informal setting were included in the model. These variables accounted for a significant amount of variance in the model, $R^2 = 0.172$, $F(2, 98) = 10.148$ $p < 0.001$. Further the interaction term was added to the model. This interaction accounts for a less significant amount of variance in the error rates on no-go trials (20-80 proportion), R^2 change = 0.034, *F change* (1, 97) = 4.169, $\beta = -0.004$, $t(97) = -2.042$, $p = 0.044$. Examination of the interaction plot showed a diminishing effect that with higher L1 proficiency and L1 use in informal setting, error rates on no-go trials (20-80) decrease. High L1 proficiency was associated with comparable no-go errors in case of low, average or high L1 use in informal settings. Low L1 proficiency with highest use of L1 in informal setting was associated with highest no-go error rates.

Model 3: mediation analysis In step 1 of the mediation model, the regression of L1 self-reported proficiency on no-go error (20-80 proportion), ignoring the mediator, was significant, $b = -0.104$, $t(99) = -3.571$, $p < 0.001$. Step 2 showed that the regression of L1 proficiency on L1 use in informal settings, was also significant, $b = 0.633$, $t(99) = 3.381$, $p = 0.001$. Step 3 of the mediation process showed that the mediator (L1 use in informal settings), controlling for L1 proficiency, was significant, $b = 0.040$, $t(98) = 2.607$, $p = 0.010$. Step 4 of the analyses revealed that, controlling for the mediator (L1 use in informal settings), L1 proficiency was a significant predictor of no-go error rates (20-80), $b = -0.130$, $t(98) = -4.317$, $p < 0.001$ (see Fig. 7). It was found that use of L1 in informal settings partially mediated the relationship between L1 proficiency and inhibitory control (no-go error rates).

Discussion

We examined the relationship between L1/L2 proficiency and inhibitory control as moderated by sociolinguistic factors such as language use across settings, exposure, frequency of switching and non-language variables such as working memory, socioeconomic status and other skills (sports, music etc.). The results suggest that (a) L1 proficiency predicted the no-go error rates in both 80-20 and 20-80 proportion conditions with high and low inhibitory demands respectively; (b) L2 proficiency predicted no-go error rates only in the high monitoring (50-50 proportion) condition; (c) inhibitory control in a high monitoring condition is predicted by higher L2 proficiency and is further moderated by contextual switching. When the L2 proficiency is high, rate of contextual switching did not affect the no-go error rates in a high monitoring condition whereas when the L2 proficiency is low, no-go error rates increased with increase in the rate of contextual switching; (d) L1 proficiency predicted inhibitory control in a less demanding condition with 20-80 proportion moderated by the use of L1 in informal settings; (e) this was further explained by mediation analysis suggesting that use of L1 partially mediated and improved the strength of the relationship between L1 proficiency and inhibitory control; (f) The relationship between proficiency and inhibitory control was not modulated by fluid intelligence, socioeconomic status and participation in skilled activities.

These results suggest that higher the L1/L2 proficiency lesser will be the error rates on No-go trials. L2

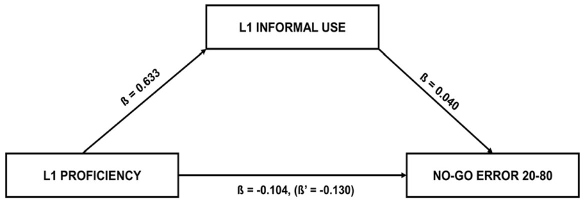

Fig. 7 Mediation model depicting the regression coefficients for the relationship between L1 proficiency and inhibitory control (no-go error rates: 20-80 proportion condition) as mediated by L1 use in informal settings

proficiency more strongly predicted inhibitory control in a high monitoring condition. These findings are consistent with the earlier results pertaining to the relationship between L2 proficiency and executive control (Singh and Mishra 2012, 2013) as well as inhibitory control (Dash and Kar 2020) suggesting that high L2 proficiency is associated with better executive and/or inhibitory control. Moreover, the 50-50 proportion condition of go/no-go trials requires the recruitment of proactive control as both kinds of trials are equiprobable and L2 proficiency and contextual switching interactively predicted inhibition in a condition high on proactive control. Effect of L2 proficiency on proactive inhibitory control has been demonstrated in a cued go/no-go task with reduced proactive inhibition cost among high proficiency (L2) bilinguals (Singh and Kar 2018). There is evidence to suggest that bilingual advantage on tasks measuring cognitive control is modulated by task demand (Costa et al. 2009; Jiao et al. 2017). The relationship between L2 proficiency and inhibitory control was moderated by factors involved in language control such as contextual bilingual switching. Contextual switching is a measure of switching behavior in the context of certain situations or environment (Rodriguez-Fornells et al. 2012). Contextual switch appears because of the contextual cues in the environment that trigger the activation of the target language and competition from the non-target language due to which we find that contextual switch moderates the relationship between proficiency and inhibitory control. It is important to note here that self-reported switching behaviour in bilinguals need to be validated with more objective measures developed for Indian context.

The effect of L2 proficiency on inhibitory control was independent of the effect of variables such as language use across settings. Although, regression analysis showed significant relationship between L2 informal use and error rates on no-go trials in the 80-20 proportion condition with greater demand on inhibitory control yet, the moderation model was not significant. These results suggest that L2 use and L2 proficiency may have an independent and not an interactive effect on inhibitory control. This could also be due to the fact that L2 use in informal settings is less dominant in the target population.

Cognitive outcomes of bilingualism also vary depending on the kind of bilingual experience. Macnamara and Conway (2014) claims that the cognitive benefit will be specific to the kind of bilingual management demand exerted by the bilingual processing mechanisms involved. This is also in line with the assumptions of adaptive control hypothesis that different interactional contexts impose different cognitive demands arguing for adaptive cognitive control of the situation. Our findings suggest that different sociolinguistic factors influence (directly or indirectly) different task demands and it is possibly due to the same reasons claimed by Macnamara and Conway (2014) as well as the adaptive control hypothesis.

Interestingly, L1 proficiency predicted inhibitory control and this relationship was only weakly moderated by sociolinguistic factors. This is consistent with our earlier study in which L1 proficiency predicted the behavioural and neural correlates of inhibitory control (Dash and Kar 2020). However, the current study also showed the moderating and mediating effect of setting-based use of L1 on the interaction between L1 proficiency and inhibitory control.

General discussion

We examined the relationship between language proficiency in both first and second language with inhibitory control as modulated by sociolinguistic (language switching, age of acquisition of L2, language exposure, language use in formal and informal setting) and non-language (fluid intelligence, socioeconomic status, working memory, skills) factors. Two methodologies were adopted: Study 1 examined the effect of bilingualism on inhibitory control by treating language proficiency as a categorical variable (following a factorial design). Study 2 adopted a correlational design to examine the relationship between L1/L2 proficiency and inhibitory control. Sociolinguistic and non-language factors were taken as covariates in Study 1 and moderator variables in Study 2 while taking proficiency as an independent measure and performance on go/no-go task as the dependent measure.

Study 1 demonstrates that high proficient bilinguals showed better inhibitory control (less error rates on no-go trials) when the demand on withholding the response was high in a go/no-go task. This was supported by the findings of the second study with a correlational design showing a significant relationship between L1/L2 proficiency and inhibitory control. More specifically, L2 proficiency predicted inhibitory control in a high monitoring condition in terms of proactive control (50-50 proportion of go/no-go trials) whereas L1 proficiency predicted performance irrespective of the demands on inhibitory control. These findings suggest that L2 may involve greater recruitment of inhibitory control for language control mechanisms, and thus shows an effect on inhibitory control required to inhibit a pre-potent response on no-go trials only when the demand on monitoring is significantly high. These findings support the BICA hypothesis and are against the BEPA hypothesis (Hilchey and Klein 2011). In a bilingual context, demand is high on goal maintenance and monitoring of the language in use more for the second language.

Secondly, the covariate analysis in Study 1 showed that none of the non-language factors influenced the interaction between proficiency as a measure of bilingualism and inhibitory control (no-go errors). These findings are supported by the correlational design followed in Study 2 ruling out the criticism that the relationship between bilingualism and cognitive control is influenced by such factors (Paap et al. 2015). However, as expected, the sociolinguistic factors such as language use in formal and informal settings, exposure to L1/L2, and frequency of switching from L2 to L1 influenced the interaction between proficiency and inhibitory control. These results were further pruned in the second study. Although, proficiency when treated as a categorical variable showed the influence of more language/sociolinguistic factors associated with both languages on the interaction between proficiency and inhibitory control, yet only setting-based use of language and contextual switching survived the moderation/mediation effect of these factors on the interaction between L1/L2 proficiency and inhibitory control. This may lead to two speculations, one that there is heterogeneity in the way L1/L2 proficiency may interact with other factors associated with bilingual experience and influence cognitive control; on the other hand one may deduce that L1/L2 proficiency and a set of contextual factors could be taken as a composite measure of bilingualism (Sulpizio et al. 2020) in defining the degree of bilingualism. Moreover, the participants of the current study included student volunteers (L1 being Hindi and L2 being English) from University of Allahabad. In general, the language use in the study group is driven by the context in terms of the settings (formal or informal) and domain of language use (speaking/listening or reading/writing) resulting in less code mixing in spoken language and rather maintaining a language set which may influence language control. This is consistent with the findings of the study related to the moderating effect of contextual switching and setting-based language use.

Setting-based use of L1 and L2 was found to predict inhibitory control in the current study and L1 use moderated the interaction between language proficiency and inhibitory control. According to the adaptive control hypothesis (Green and Abutalebi 2013), language use determines how a to-be used language is kept active while inhibiting the not-to be used language, and therefore may explain the interaction between language use and domain general inhibitory control in bilinguals. If language use is an important factor affecting the plasticity across language and control networks (Li et al. 2015) then both L1 and L2 usage should be considered, given the long-term use of both languages among bilinguals.

One of the recent studies on the functional connectivity of language control network and cognitive control network offers a more comprehensive approach by looking at bilingual experience as a function of the joint effect of age of acquisition of L2, L2 proficiency and usage while investigating the effect of bilingualism on brain plasticity involving language control (Sulpizio et al. 2020). Authors find that proficiency and language use as dynamic factors modulate the functional connectivity within and between language and control networks. The findings of the current study are consistent with this work, in showing a significant interaction between proficiency and language use as measures of bilingualism and cognitive control. However, the current study extends it further as we investigated the role of both L1 and L2 proficiency towards inhibitory control since the level of L1 and L2 proficiency varies among bilinguals and are likely to be differently affected by sociolinguistic factors. Rather than taking the combined measure of bilingual experience (proficiency, language use, age of acquisition) we first needed to examine the independent interactions between variables such as setting-based use of L1 and L2 with language proficiency. Study 1 showed that even though L1 proficiency was matched between the two groups, they differed with respect to the use of L1 in spoken language (Table 1). However, L1 use in formal as well as informal settings affected the interaction between proficiency and inhibitory control. This was further addressed in Study 2 which showed that L1 use moderated the relationship between L1 proficiency and inhibitory control. Therefore, it was important to sort out the role of sociolinguistic factors because all the factors do not similarly influence proficiency and thereby its interaction with cognitive control. In addition, factors such as setting-based language use may not simply add up to proficiency rather seem to modulate the interaction between proficiency and cognitive control. The study cohort in the current study could be more heterogeneous or diverse for future studies with respect to non-language variables, since the current study mostly included university students which is one of the limitations of the study.

The findings of the current study have implications for other similar bilingual contexts in which setting-based use of languages known to an individual is a dominant aspect of bilingual experience. These findings could also be validated with other bilingual and multilingual contexts with other Indian languages to enhance the generalizability of the current findings. However, the current study provides interesting insights into the complexity of the relationship between language proficiency and its variable interaction with specific sociolinguistic factors such as setting-based language use and contextual switching which may influence cognitive outcomes related to bilingualism. It is to be noted that research on bilingualism and cognitive control has shown comparable results across cultures. Bialystok and Viswanathan (2009) found that bilingual children in India and Canada outperformed monolinguals in Canada in inhibitory control and cognitive flexibility. Despite being from different cultural backgrounds and immigration status, bilingual children in India and Canada performed at comparable level. Similarly, Bialystok et al (2010) and Barac and Bialystok (2012) found generality of cognitive outcomes in bilingual children across different cultures. However, experience dependent cognitive outcomes may vary largely across different cultures and need to be explored in future.

Conclusion

The current study demonstrates the relationship between L1/L2 proficiency and inhibitory control under varying demands on inhibitory control and monitoring. We find that long-term bilingual experience implying the continuous involvement in activation/inhibition of the languages known to a bilingual, contributes to cognitive control. L2 proficiency seems to be driven more by language control variables whereas setting-based use modulates the relationship between L1 proficiency and control. Future research needs to continue to conceptualize bilingual experience as a continuous and multifactorial measure while investigating the interaction between bilingualism and cognitive control. Extending this line of research, it would be imperative to look at both L1 and L2 proficiency. Future work may also include an objective measure of interactional context as one of the important sociolinguistic factors (de Bruin, 2019) as well as L1/L2 immersion and its role in defining bilingual experience as it interacts with control mechanisms.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Appendix

See Table I.

Table I Mean and standard deviation for the language and nonlanguage measures for Study 2

Language measures	Mean (SD)
Picture description (L1)	15.1 (3.36)
Picture description (L2)	12.79 (3.56)
Picture naming (L1)	43.57 (2.99)
Picture naming (L2)	40.75 (4.41)
Auditory comprehension (L1)	3.66 (1.06)
Auditory comprehension (L2)	3.11 (1.27)
LexTALE	71.89 (11.23)
Overall self-rated proficiency (L1)	59.46 (7.21)
Overall self-rated proficiency (L2)	49.20 (10.73)
L1 switch	9.54 (1.86)
L2 switch	9.45 (1.91)
Contextual switch	9.81 (2.22)
Unintended switch	7.60 (2.37)
Overall language switch	19 (2.96)
Formal use of L1	45.63 (20.50)
Informal use of L1	58.95 (14.19)
Formal use of L2	54.10 (20.41)
Informal use of L2	40.88 (14.23)
Exposure duration of L1	67.18 (15.72)
Exposure duration of L2	33.02 (15.37)
Age of L2 acquisition	7.48 (3.28)

References

Barac, R., & Bialystok, E. (2012). Bilingual effects on cognitive and linguistic development: Role of language, cultural background, and education. *Child Development, 83*(2), 413–422.

Barac, R., Moreno, S., & Bialystok, E. (2016). Behavioral and electrophysiological differences in executive control between monolingual and bilingual children. *Child Development, 87*(4), 1277–1290.

Bialystok, E. (2016). The signal and the noise: Finding the pattern in human behavior. *Linguistic Approaches to Bilingualism, 6*(5), 517–534.

Bialystok, E., & Barac, R. (2012). Emerging bilingualism: Dissociating advantages for metalinguistic awareness and executive control. *Cognition, 122*(1), 67–73.

Bialystok, E., Craik, F. I., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging, 19*(2), 290.

Bialystok, E., Luk, G., Peets, K. F., & Yang, S. (2010). Receptive vocabulary differences in monolingual and bilingual children. *Bilingualism (Cambridge, England), 13*(4), 525–531.

Bialystok, E., & Viswanathan, M. (2009). Components of executive control with advantages for bilingual children in two cultures. *Cognition, 112*(3), 494–500.

Blanco-Elorrieta, E., & Pylkkänen, L. (2018). Ecological validity in bilingualism research and the bilingual advantage. *Trends in Cognitive Sciences, 22*, 1117–1126.

Blumenfeld, H. K., & Marian, V. (2013). Cognitive control and parallel language activation during word recognition in bilinguals. *Journal of Cognitive Psychology, 25*, 547–567.

Bruin, K., & Wijers, A. (2002). Inhibition, response mode and stimulus probability: A comparative event-related potential study. *Clinical Neurophysiology, 113*, 1172–1182.

Christoffels, I. K., Firk, C., & Schiller, N. O. (2007). Bilingual language control: An event-related brain potential study. *Brain research, 1147*, 192–208.

Christoffels, I. K., Kroll, J. F., & Bajo, M. T. (2013). Introduction to bilingualism and cognitive control. *Frontiers in Psychology, 4*, 199. https://doi.org/10.3389/fpsyg.2013.00199.

Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition, 113*(2), 135–149.

Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition, 106*(1), 59–86.

Cox, S. R., Bak, T. H., Allerhand, M., Redmond, P., Starr, J. M., Deary, I. J., et al. (2016). Bilingualism, social cognition and executive functions: A tale of chickens and eggs. *Neuropsychologia, 91*, 299–306.

Crespo, K., Gross, M., & Kaushanskaya, M. (2019). The effects of dual language exposure on executive function in Spanish–English bilingual children with different language abilities. *Journal of Experimental Child Psychology, 188*, 104663.

Dash, T., & Kar, B. R. (2012). Characterizing language proficiency in Hindi and English language: Implications for bilingual research. *International journal of mind brain and cognition, 3*(1), 73–105.

Dash, T. & Kar, B. R. (2014). Bilingual language control and general purpose cognitive control among individuals with bilingual aphasia: Evidence based on negative priming and flanker tasks. *Behavioural Neurology, 679706*

Dash, T., & Kar, B. R. (2020). Behavioural and ERP correlates of bilingual language control and general purpose inhibitory control predicted by L1 and L2 proficiency. *Journal of Neurolinguistics, 56*, 100914. https://doi.org/10.1016/j.jneuroling.2020.100914.

De Bruin, A. (2019). Not All Bilinguals are the same: A call for more detailed assessments and descriptions of bilingual experiences. *Behavioural Sciences, 9*, 33. https://doi.org/10.3390/bs9030033.

Dong, Y., & Xie, Z. (2014). Contributions of second language proficiency and interpreting experience to cognitive control differences among young adult bilinguals. *Journal of Cognitive Psychology, 26*, 506–519.

Engel de Abreu, P. M., Cruz-Santos, A., Tourinho, C. J., Martin, R., & Bialystok, E. (2012). Bilingualism enriches the poor: Enhanced cognitive control in low-income minority children. *Psychological science, 23*(11), 1364–1371.

Festman, J., Rodriguez-Fornells, A., & Münte, T. F. (2010). Individual differences in control of language interference in late bilinguals are mainly related to general executive abilities. *Behavioural and Brain Functions, 6*, 5.

Fishman, J. A., & Cooper, R. L. (1969). Alternative measures of bilingualism. *Journal of Verbal Learning and Verbal Behavior, 8*(2), 276–282.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and cognition, 1*(2), 67–81.

Green, D. W. (2011). Language control in different contexts: The behavioral ecology of bilingual speakers. *Frontiers in Psychology, 2*, 103. https://doi.org/10.3389/fpsyg.2011.00103.

Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology, 25*(5), 515–530.

Hilchey, M. D., & Klein, R. M. (2011). Are there bilingual advantages on nonlinguistic interference tasks? Implications for the plasticity of executive control processes. *Psychonomic Bulletin and Review, 18*(4), 625–658.

Iluz-Cohen, P., & Armon-Lotem, S. (2013). Language proficiency and executive control in bilingual children. *Bilingualism: Language and Cognition, 16*(4), 884–899.

Jiao, L., Liu, C., Wang, R., & Chen, B. (2017). Working memory demand of a task modulates bilingual advantage in executive functions. *International Journal of Bilingualism, 23*(1), 102–117.

Khare, V., Verma, A., Kar, B., Srinivasan, N., & Brysbaert, M. (2013). Bilingualism and the increased attentional blink effect: Evidence that the difference between bilinguals and monolinguals generalizes to different levels of second language proficiency. *Psychological Research Psychologische Forschung, 77*(6), 728–737.

Kroll, J. F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for language processing and cognition. *Journal of cognitive psychology, 25*(5), 497–514.

Kroll, J. F., Bobb, S. C., & Wodniecka, Z. (2006). Language selectivity is the exception, not the rule: Arguments against a fixed locus of language selection in bilingual speech. *Bilingualism: Language and Cognition, 9*(2), 119–135.

Lemhöfer, K., & Broersma, M. (2012). Introducing LexTALE: A quick and valid lexical test for advanced learners of English. *Behavior Research Methods, 44*(2), 325–343.

Li, L., Abutalebi, J., Zou, L., Yan, X., Liu, L., Feng, X., et al. (2015). Bilingualism alters brain functional connectivity between “control” regions and “language” regions: Evidence from bimodal bilinguals. *Neuropsychologia, 71*, 236–247.

Luk, G., & Bialystok, E. (2013). Bilingualism is not a categorical variable: Interaction between language proficiency and usage. *Journal of Cognitive Psychology, 25*(5), 605–621.

Luk, G., De Sa, E. R. I. C., & Bialystok, E. (2011). Is there a relation between onset age of bilingualism and enhancement of cognitive control? *Bilingualism: Language and cognition, 14*(4), 588–595.

Macnamara, B. N., & Conway, A. R. (2014). Novel evidence in support of the bilingual advantage: Influences of task demands and experience on cognitive control and working memory. *Psychonomic Bulletin and Review, 21*(2), 520–525.

Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods, 44*(2), 314–324. https://doi.org/10.3758/s13428-011-0168-7.

Michael, E. B., & Gollan, T. H. (2005). Being and becoming a bilingual: Individual differences and consequences for language production. In J. F. Kroll & A. M. B. De Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 389–410). New York: Oxford University Press.

Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective, and Behavioral Neuroscience, 3*, 17–26.

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive psychology, 66*(2), 232–258.

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

Qu, L., Low, J. J. W., Zhang, T., Li, H., & Zelazo, P. D. (2015). Bilingual advantage in executive control when task demands are considered. *Bilingualism: Language and Cognition, 19*(2), 277–293.

Raven, J., Raven, J. C., & Court, J. H. (2000). *Manual for Raven's progressive matrices and vocabulary scales*. Oxford: Oxford Psychologists Press.

Rodriguez-Fornells, A., Kramer, U., Lorenzo-Seva, U., Festman, J., & Münte, T. F. (2012). Self-assessment of individual differences in language switching. *Frontiers in Psychology, 2*, 388.

Rosselli, M., Ardila, A., Lalwani, L. N., & Vélez-Uribe, I. (2016). The effect of language proficiency on executive functions in balanced and unbalanced Spanish–English bilinguals. *Bilingualism, 19*, 489–503.

Singh, J. P., & Kar, B. R. (2018). Effect of language proficiency on proactive occulo-motor control among bilinguals. *PLoS ONE, 13*(12), e0207904.

Singh, J. P., Prasad, S., & Mishra, R. K. (2019). Language proficiency in bilinguals enhances action preparedness and control. *Journal of Cultural Cognitive Science, 3*(1), 75–90.

Singh, N., & Mishra, R. K. (2012). Does language proficiency modulate oculomotor control? Evidence from Hindi–English bilinguals. *Bilingualism: Language and Cognition, 15*(4), 771–781.

Singh, N., & Mishra, R. K. (2013). Second language proficiency modulates conflict-monitoring in an oculomotor Stroop task: Evidence from Hindi–English bilinguals. *Frontiers in Psychology, 4*, 322.

Singh, N., & Mishra, R. K. (2015). The modulatory role of second language proficiency on performance monitoring: Evidence from a saccadic countermanding task in high and low proficient bilinguals. *Frontiers in Psychology, 5*, 1481.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6*, 174.

Sullivan, M. D., Janus, M., Moreno, S., Astheimer, L., & Bialystok, E. (2014). Early stage second-language learning improves executive control: Evidence from ERP. *Brain and Language, 139*, 84–98.

Sulpizio, S., Maschio, N. D., Mauro, G. D., Fedeli, D., & Abutalebi, J. (2020). Bilingualism as a gradient measure modulates functional connectivity of language and control networks. *Neuroimage, 205*, 116306. https://doi.org/10.1016/j.neuroimage.2019.116306.

Verhagen, J., de Bree, E., & Unsworth, S. (2020). Effects of bilingual language use and language proficiency on 24-month-olds' cognitive control. *Journal of Cognition and Development, 21*, 46–71. https://doi.org/10.1080/15248372.2019.1673752.

Verreyt, N., Woumans, E., Vandelanotte, D., Szmalec, A., & Duyck, W. (2016). The influence of language-switching experience on the bilingual executive control advantage. *Bilingualism, 19*, 181–190.

Wu, Y. J., & Thierry, G. (2013). Fast modulation of executive function by language context in bilinguals. *Journal of Neuroscience, 33*(33), 13533–13537.

Xie, Z. (2018). The Influence of second language (L2) proficiency on cognitive control among young adult unbalanced Chines–English bilinguals. *Frontiers in Psychology, 9*, 412. https://doi.org/10.3389/fpsyg.2018.00412.

Yang, H., Hartanto, A., & Yang, S. (2016). The complex nature of bilinguals' language usage modulates task-switching outcomes. *Frontiers in Psychology, 7*, 560. https://doi.org/10.3389/fpsyg.2016.00560.

Yang, H., & Yang, S. (2017). Are all interferences bad? Bilingual advantages in working memory are modulated by varying demands for controlled processing. *Bilingualism: Language and Cognition, 20*(1), 184–196.