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Social facilitation and bilingual cognitive advantage: Bridging social psychology and psycholinguistics

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ABSTRACT

This study examined the role of social context in the expression of the bilingual cognitive advantage in 145 bilingual university students. All participants mastered Arabic as their native language (L1), but half were highly proficient in French (high L2 group), whereas half were less proficient (low L2 group). A color-word Stroop test with incongruent, congruent and neutral stimuli was administered in single language blocks (Arabic or French words) or in a mixed block (Arabic and French words), either under social presence, or alone. Stroop interference was analyzed to assess the cost of resolving conflict in incongruent trials and was compared across groups and experimental conditions. If bilingualism comes with a cognitive advantage, a reduction of interference in high (vs. low) L2 proficient subjects is to be expected. Analysis revealed that interference was significantly reduced in high L2 group, but only under the single language condition. Furthermore, whereas social context and sex had no main effects, analysis revealed a significant 4-factor interaction between L2 proficiency, linguistic context, social context, and sex. Social presence further reduced interference (social facilitation) in high L2 proficient females, but not in males. Overall, the results suggest that mastering a second language comes with cognitive advantages which adapt dynamically to social and linguistic contexts in a sex-dependent manner. We argue that advancing bilingualism research requires more attention to the social environment.

1. Introduction

The bilingual cognitive advantage (BICA) hypothesis holds that bilinguals develop greater domain-general cognitive capacities [1]. The core rationale is that the two (or more) languages are active simultaneously and continuously in the bilingual's mind, even when the context requires only one of them, leading to strengthened executive functions with positive consequences for non-linguistic tasks. This hypothesis has originally received strong support from neuroscientific studies showing that bilingualism reconfigures the brain's structure and function, through neuronal plasticity, and that brain activations involved in the control of two languages overlap

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significantly with those of executive functions (for reviews, see Refs. [2–6]).

However, the BICA hypothesis has also been highly controversial (e.g. Refs. [7,8]), with some researchers suggesting that bilingualism may not have a specific effect, but a benefit shared with other prolonged experiences, such as musical training or intensive video-game playing (e.g. Ref. [9]), while others claim that it may not have any effect at all [10,11]. A recent bibliometric review found that, whereas initial studies provided support for the bilingual advantage, the number of studies not supporting this hypothesis has increased significantly since 2014, to exceed the number of those supporting the advantage in 2017 [12]. Even when studies reported an advantage, the effect size has been highly debated, and several meta-analysis reviews have assessed the strength of the reported effects in relation with various suspected biases [13–18]. For example, Lehtonen et al. [17] made an extensive meta-analysis including 152 studies and 891 comparisons controlling for a number of potential biases, including executive function domains (inhibitory control, set shifting, working memory, monitoring, attention and verbal fluency), tasks and paradigms used, stimulus types (verbal, non-verbal), language of testing (L1, L2), practices in group matching (IQ, SES, vocabulary size), various participants' variables (age, age of L2 acquisition, level of L2 proficiency, immigration status …) and even the country where the studies were conducted. The study concluded that, after controlling for these variables, the remaining effect attributable to bilingualism was minor or absent depending on the executive function domain. A similar conclusion was reached by other reviews (e.g. Refs. [15,18]).

However, if musical training (e.g. Refs. [19,20]), intensive video-game playing (e.g. Ref. [21]), or team-sports for example (e.g. Ref. [18]), can enhance cognitive abilities, it would seem rather puzzling that bilingualism, which is an intense and integrative human activity, does not bring advantages to general cognition and executive function. If we assume that such advantages do indeed exist, but that they may not extend to all bilinguals under all circumstances, we are required to look into which factors moderate their expression. To this end, recent efforts focused on explanations related to the diversity of individual language experiences in bilingual speakers. In particular, rather than considering bilinguals as a homogeneous category, often compared to monolinguals, research should consider individual experiences with their specific background and outcomes (e.g. Refs. [7,22,23]). While this approach opens new perspectives, with emphasis on past experiences and individual variability, we should also consider how bilinguals adapt to specific linguistic and social contexts (see Refs. [24,25]).

Social context: the missing piece to the puzzle?

So far little attention has been devoted to the social context when assessing the bilingual advantage. In his review on "Invariants of human behavior", concluding on measuring performance in cognitive psychology (p. 16), Herbert A. Simon [26] stated: *"But since the performance depends heavily on socially structured and socially acquired knowledge, it must pay constant attention to the social environment of cognition."* In a cognitive domain as complex as bilingualism, the social environment might be highly critical. In his recent book, Mishra [25] has advocated the need to put experimental work in context, including social context. Mishra and his collaborators found, for example, that just as cultural cues that represent the culture of a given language facilitate activation of that language, social cues (e.g., identity of the interlocutor) are also key factors for adaptive capacities of the bilingual speaker (e.g. Refs. [27–32]).

Another, perhaps most fundamental invariant of social context and social behavior, which has not been addressed so far, relates to the mere presence of others, including the experimenter. Social psychology has studied this phenomenon for more than a century since the pioneering work of Triplett [33], and has demonstrated that mere presence may improve (social facilitation) or impair (social impairment) performance on a variety of tasks and behaviors, not only in humans, but in most animal species (e.g. Refs. [34–38]). Critically, even minor variations in the social environment, such as the location of the experimenter relative to the participant, whether they were visible/invisible to the participant, if and how they interacted with the subject during the testing session, may have profound effects on performance [39]. The mechanisms of this social modulation have been largely debated, but it is widely accepted that mere presence of others influences cognitive performance by consuming attentional resources (e.g. Refs. [34,40]). Given that language is a communicative skill, fundamentally rooted in social interactions/communication and sociocultural representations, one would expect mere presence to have major implications when assessing bilingual cognitive advantage. Interestingly, Bhatia et al. [28] reported modulation of language processes in adult bilinguals using cartoons to symbolically represent interlocutors. If language selection in bilinguals is influenced by a simple symbolic representation of potential others, and if mere presence of others consumes executive attention, then subtle variations in the experimenter's presence and/or behavior from one study to another, or from one participant to another within the same study, might cause drastic changes in performance, with potential consequences of reducing or enhancing group differences and thus leading to contradictory findings.

Aims of the present study

The present study was undertaken primarily to examine the potential role of social context in the moderation of bilingual advantage. We used the color-word Stroop test, which requires subjects to inhibit a highly automatic task while focusing attention on a less automatic one [41,42] and the social facilitation paradigm. Stroop interference (SI), a measure of the cost of resolving the conflict between the distractor and the task, has been shown to be inversely correlated with the cognitive advantage: the greater the advantage, the lower the SI [43–46]. The study used SI to quantify the advantage in two groups of bilingual participants which differed in the level of L2 proficiency (high vs. low L2 proficiency). Our assumption was that if bilingualism comes with an advantage, high L2 proficient participants would show reduced interference. Our main question then was whether this reduced interference (cognitive advantage) would depend on social context, i.e., when participants performed the Stroop task under social presence versus social isolation. The study design controlled for other factors, namely linguistic context and sex, in order to assess their potential interactions with social context.

2. Methods

2.1. Participants

In Morocco, all university students master spoken Arabic as their native language (L1) and have learned French as their second language (L2) in school. However, their L2 proficiency is usually higher in Science, Medical and Engineering Schools, where French (L2) is intensively used for teaching and communication, compared to Humanities, where Literary Arabic is used instead of French. To compare participants with different levels of L2 proficiency, we thus targeted students of the Medical School (MS) and those of the Law School (LS), with the assumption that MS participants would have a higher mastery of L2 than LS subjects. A total of 146 third-year students were recruited (73 from each School), whose age varied between 20 and 24 years (MS, 20.78 ± 0.71; LS, 21.64 ± 1.08). All participants were volunteers and gave written consent to take part to the study in accordance with the Declaration of Helsinki. The study was approved by the local ethics committee of the University Hospital of Fes (Morocco), under the number *04/2019*, and the data were handled in full confidentiality throughout the experiment.

To quantify the level of L2 proficiency of our participants, we used an auto-questionnaire which included their ability to understand, write and speak French, their age of immersion and acquisition of French (before or after the age of 6 years), the language they used to rehearse colors during the test (French, Arabic or none), the degree to which they used French at home, with friends and on

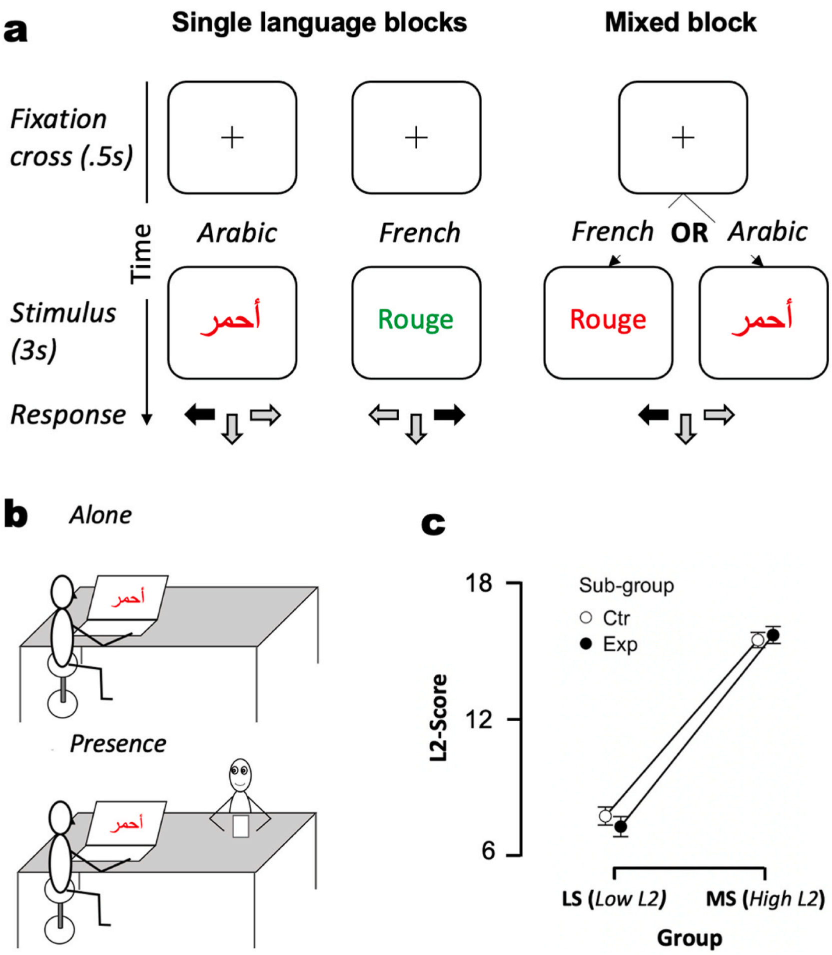

Fig. 1. Experimental design and language groups. a. Design. The squares depict the state of the computer screen at key times of a trial, with the time flow shown on the left side. Examples of trials are represented for single language blocks (Arabic, left; French, middle), and for a mixed block (right). A trial starts with a fixation cross for .5s (top panels), followed by a word or a sting of "+" signs (not illustrated). The subject was required to respond by pressing one of three keys (arrows). The correct response is depicted in black. b. Setup and social conditions. The subject performed the task under social isolation (Alone) or social presence (Presence). In the Presence condition, a cartoon represents the confederate (audience) sitting across the table with an angle of 45° to the right of the subject. c. Assessment of L2 proficiency using L2-Score for French. Comparison between groups (LS, Law School; MS, Medical School), and sub-groups (Ctr, Control = Alone + Alone; Exp, Experimental = Alone + Presence). L2-Score was significantly higher in MS than in LS group ($F (1,143) = 440.571$; $p < .001$; $\eta_p^2 = 0.755$), but not across sub-groups ($p = .84$). In the following figures, LS and MS will be termed low and high L2 proficient groups, respectively.

social media, and the degree to which they code-switched between Arabic and French. A composite L2-Score, inspired by the LEAP-Q score of Marian et al. [47] was calculated and compared across groups using statistical tools (see Results).

In addition, we collected socio-economic data, including parental education and occupational status to compute a socio-economic status (SES) score. In order to assess the level of our participants' sensitivity to social context, we used an online Liebowitz Social Anxiety Scale (LSAS), translated to French and Arabic.

2.2. Experimental design

All the participants were tested by the same investigator (AB), between 2 and 7 p.m., in the same room and setting, in a single session that lasted less than 60 min. He interacted with MS participants in French (their academic language), and with LS participants in Arabic (L1). Similarly, all verbal and written instructions during testing were given in the corresponding language. Participants were naïve as to the main study objectives, and each of them was asked to fill the auto-questionnaire designed to collect personal, socio-economic, and linguistic information.

Study design in a nutshell. The experiment was run on a laptop using PsychoPy [48]. Words were presented on the computer screen and the subjects responded by pressing a key on the computer keyboard. The study design is summarized in Fig. 1. Briefly, on a given trial, the subject was presented with a color-word in either Arabic or French, or with a string of colored "+" signs and had to report the font color (Fig. 1a). The design included 3 blocks: two single-language blocks, with words in Arabic or French, with "+" items, and one block of mixed languages. These 3 blocks were administered to each subject under complete social isolation (Alone) or under social presence (Presence; Fig. 1b). Finally, the sequence of 6 blocks (3 Alone + 3 in Presence) was selected following a Williams' design (See Procedure below).

Training block. The experiment began with a block of neutral non-color words in both languages (Table: table, طاولة; Book: livre, كتاب; Chair: chaise, كرسي; Glass: verre, كأس; Tree: arbre, شجرة; Dog: chien, كلب; Bike: vélo, دراجة; Car: voiture, سيارة), written in the 3 colors used in the Stroop test (red, blue, green). The block contained 48 combinations (i.e., 48 trials) of intermixed Arabic and French words drawn randomly.

Stroop test. After the training trials, three blocks of the Stroop test were administered: two single-language blocks, one in Arabic and one in French, and a mixed-language block where French and Arabic color words were intermixed with control stimuli.

In the single-language Stroop test, we used 3 color naming words (red, blue, green), and control stimuli ("+" signs) written in one of these three colors, in Arabic or in French. There were three categories of stimuli: incongruent (e.g., the word "red" written in green color; response "Green = right"), congruent (e.g., the word "green" written in green color; response "Green = right") and control stimuli (e.g., the signs "+" written in green; response "Green = right"). We used the French/Arabic words rouge/أحمر (red), bleu/أزرق (blue), vert/أخضر (green), and strings of 3 or 4 "+" signs. Incongruent, congruent and control stimuli were presented randomly, and were repeated 30 times each, with a total of 90 trials in the French block and 90 trials in the Arabic block.

In the mixed-language Stroop test, the same French and Arabic color words used in the single-language blocks were intermixed with control stimuli and drawn randomly for language, color, and stimulus type. Each stimulus was repeated 5 times, with a total number of 150 trials (30 controls; [30 congruent + 30 incongruent] x 2 languages).

Social presence effect. To study the effect of mere presence, half of the participants of each group (experimental sub-groups) were administered the three Stroop blocks under two conditions: in one condition, the participant was alone in the testing room; in the other, a person (termed "audience") was present while the participant performed the task, with the exclusion of the training block, which was always performed alone. To control for a potential effect of practice, the other half of participants (control sub-groups) were tested twice under the alone condition.

2.3. Procedure

To minimize inter-subject variability as to how participants perceived another person's presence, we did our best to make the procedure as standardized as possible across participants. For the Alone condition, after the investigator provided the participant with all the information, he simply said: "I let you start, I will be in my office next door, please let me know when you are done", and left the room. At the end of the tests, a screen display prompted the participant "Please call the investigator for the next part of the experiment", in French (MS group) or in Arabic (LS group). When the participant opened the door, she/he found the investigator in front of the door, with an unfamiliar person (audience). Two young anonymous university students (one female and one male, 22 and 23 years old, respectively), were recruited specifically to play the audience role. The audience was of the same sex, and approximate age and level of education as the participant. The scenario was carefully designed to make the participant think that the presence of this person was a coincidence, and to discard any idea of evaluative presence. Finally, the investigator took great care of obtaining the consent of the participant regarding the presence of the Audience (with the question "do you mind if …").

The audience sat across the table (Fig. 1b), facing the participant from about a 45° angle, in a position that allowed her/him to see the participant's hands and face. She/he was asked to fill out a fake form. Before the experiment, the audience received clear instructions to avoid interacting with the subject or make any comments, and to alternate between looking at the subject and filling out the form, as frequently as possible, spending about 70% of the total time (about 7 min) looking at the participant's hands and face, and 30% (about 3 min) of the time filling out the form.

To control for potential effects of the order of block presentation, we used a Williams' Latin-square 3*3 design [49], which offers a balanced cross-over design in six sequences. Each sequence contained a set of six blocks, three of which were administered under social presence, and three under the alone condition. Subjects were randomized in equal numbers of six possible sequences, each sequence including the six blocks (Table 1).

Data acquisition and analysis: PsychoPy generated excel files containing trial-by-trial measures of reaction times (RT) and accuracy of behavioral responses (correct vs. incorrect responses). The data were processed to extract trial-by-trial reaction RT and percentage of correct responses (PCR). One subject was excluded from the analysis because he failed on the task (PCR<10%). For the remaining participants (N = 145), we calculated the median RT and PCR for each trial type (incongruent, control, congruent) and for each language (Arabic, French), which were then organized by language block (Arabic, French, Mixed) and by social condition (Alone, Presence). The data were compiled with the linguistic and socio-demographic measures in a csv excel file for statistical analyses using the JASP statistics [50].

Analysis of performance on the Stroop test typically uses RT, a measure of the speed of the subject's response. Stroop interference, calculated using RT (RT incongruent – RT control) represents the extra time required to resolve conflict between competing stimulus features [42]. Another variable often analyzed is the error rate (or its reverse, i.e., the success rate, PCR in our study), which measures response accuracy. To allow for comparison with previous studies, we have analyzed RT and PCR separately. However, we also used the Inverse Efficiency Score (IES = RT/PCR), as a measure that integrates both speed and accuracy, and sometimes referred to as the speed accuracy trade-off. IES is conceived as an observable measure of energy consumed by the cognitive system over time [51]. Such a score that gauges the amount of energy required to resolve conflict, is particularly appropriate for the present study, where task performance requires different amounts of cognitive effort depending on experimental demands. As IES is obtained by dividing time (RT in ms) by a proportion (PCR), it has been expressed in ms [52]. However, to focus on this notion of energy consumption, we will express IES in an arbitrary Energy Unit in our illustrations. For example, if a subject responded with an RT of 600 ms on control trials and took 900 ms to respond on incongruent trials, with the same success rate of PCR = .9, then IES would be 600/.9 = 666.7 Energy Units for control trials, and 900/.9 = 1000 Energy Units for incongruent trials. Stroop interference (SI) is calculated by subtracting IES for control from IES for incongruent trials. The result will assess the extra energy consumed (effort deployed) to resolve conflict generated by incongruency. In our example, the extra energy will be SI = 1000–666.7 = 333.3 Energy Units. The higher this SI value, the more energy consumption, and conversely. Stroop facilitation, on the other hand (IES congruent - IES control) would reflect the amount of energy saved in congruent trials. If congruent trials consume the same amount of energy as control trials, SF would be null. SF < zero would mean that subjects saved energy compared to controls (facilitation).

3. Results

3.1. *L2 proficiency*

Fig. 1c illustrates the L2 scores of our participants. It shows that MS students had, on average, a much higher level of mastery of L2 compared to LS students. Statistical analysis using a simple ANOVA revealed a highly significant group difference ($F_{(1,143)} = 440.571$; $p < .001$; $\eta_p^2 = 0.755$), with a particularly high effect size, explaining 76% of L2-Score variability. Based on these results, and for the sake of simplicity, MS participants will be hereafter referred to as high L2 proficient (L2p) group, whereas LS participants will be referred to as low L2p group.

3.2. *Socio-economic status (SES)*

As expected, high and low L2p groups were largely different in terms of their socio-economic status, with high SES scores in high L2p subjects, and low SES scores in low L2p subjects (Table 2). Comparison across groups using a simple ANOVA showed a significant group difference ($F_{(1,143)} = 142.864$; $p < .001$; $\eta_p^2 = 0.50$), explaining 50% variability in SES scores. In other words, L2 proficiency and SES scores co-varied and were highly correlated (Pearson's $r = 0.732$; $p < .001$).

3.3. *Social anxiety*

Contrasting with their higher SES scores, high L2p participants scored significantly lower on the LSAS avoidance measure, compared to low L2p participants ($F_{(1,143)} = 6.525$; $p = .012$; $\eta_p^2 = 0.044$), suggesting a lower sensitivity to social context. Interestingly,

Table 1
Experimental design built using a Williams 3*3 Latin square design. The design comprised six sequences (1–6, left column), each of them involving 6 blocks (1–6, third arrow). A, Arabic Stroop test; B, French Stroop test; C, Mixed-language Stroop test.

Experimental Group	Alone			Presence		
Control Group	Alone			Alone		
Sequence \ Block	1	2	3	4	5	6
1	B	A	C	B	A	C
2	A	C	B	C	A	B
3	C	B	A	B	C	A
4	C	A	B	A	C	B
5	B	C	A	C	B	A
6	A	B	C	A	B	C

Table 2
Summary of linguistic, socio-demographic and psychological assessments. Group of mean and standard deviation (std) values the participants' L2-Score, Socio-Economic Status (SES), and Liebowitz Social Anxiety Scale (LSAS) scores.

	Law School (N = 72; 36F)	Medical School (N = 73; 38F)	Group effect (p value)
Mean L2-Score (std)	7.47 (2.52)	15.61 (2.14)	<.001
Mean SES (std)	4.14 (2.38)	10.18 (3.58)	<.001
Mean LSAS Fear (std)	29.79 (11.26)	27.53 (10.01)	.208
Mean LSAS Avoidance (std)	36.25 (11.95)	31.49 (10.88)	.013

although the sex did not have a main effect on LSAS avoidance (p = .901), it tended to show a statistically significant interaction with L2p ($F_{(1,143)} = 3.518$; p = .063; $\eta_p^2 = 0.024$). A simple main effect analysis showed that high L2p male participants (but not females) scored significantly lower compared to low L2p males ($F_{(1,141)} = 9.616$; p = .002). Finally, whereas L2p had no main effect on LSAS fear scores (p = .186), these scores were significantly affected by the sex factor ($F_{(1,141)} = 3.926$; p = .049; $\eta_p^2 = 0.027$), with males scoring lower than females. In other words, males were found to be less sensitive to social presence than females, a result which will be discussed with respect to sex related socio-emotional differences.

3.4. RT, overall RT, PCR and IES

We first compared across groups (low vs. high L2p participants), the performance on Arabic words (L1) presented in a single language Stroop block under the alone condition. We analyzed RT, PCR and IES using a repeated measures ANOVA, with trial type (congruent, control, incongruent), linguistic context (single, mixed) and session (first, second) as within subject factors, and L2p (low, high) and sex (female, male) as between subject factors. We also analyzed overall RTs using linguistic context and session as within subject factors, and L2p and sex as between subject factors.

3.4.1. Response speed (RT)

As expected, RTs were shorter in high L2p group compared to low L2p group for all trial types (Fig. 2). Statistical analyses revealed that all factors, with the exception of sex, had a significant main effect on RT [trial type, ($F_{(2,286)} = 63.661$, $p < .001$, $\eta_p^2 = 0.285$); linguistic context, ($F_{(1,143)} = 5.666$, p = .019, $\eta_p^2 = 0.038$); L2p, ($F_{(1,143)} = 19.2, 03$, $p < .001$, $\eta_p^2 = 0.118$); session, ($F_{(1,143)} = 34.340$, $p < .001$, $\eta_p^2 = 0.194$)]. In addition, we found various significant interactions between 2 factors (linguistic context * sex, p = .01; session * L2p, p = .003; trial type * linguistic context, p = .023; trial type * session, p < .001) or 3 factors (trial type * linguistic context * L2p, p < .001). These differences across trial types were mostly due to longer RTs on incongruent trials compared to congruent and control trials.

3.4.2. Overall RT

As for RT by trial type, analysis of overall RTs (i.e., RTs pooled for the 3 trial types) showed that all factors, with the exception of sex, had a strong main effect on overall RT [linguistic context, ($F_{(1,141)} = 5.713$; p = .018; $\eta_p^2 = 0.039$); L2p, ($F_{(1,141)} = 15.472$, $p < .001$, $\eta_p^2 = 0.099$); session, ($F_{(1,141)} = 68.205$; $p < .001$; $\eta_p^2 = 0.326$)]. In addition, significant interactions were found between linguistic context and sex (p = .01) as well as between session and L2p (p = .003). Stated briefly, overall RTs were shorter in high L2p compared to low L2p subjects, shorter in mixed than in single language conditions, and shorter in the second session than in the first, reflecting a practice effect.

3.4.3. Response accuracy (PCR)

The PCR also varied significantly across trial types ($F_{(2,282)} = 6.03$; p = .003; $\eta_p^2 = 0.041$), with more errors on incongruent trials. However, there was no group effect, whether as a main factor or in interaction with linguistic context (p > .5). Interestingly, L2

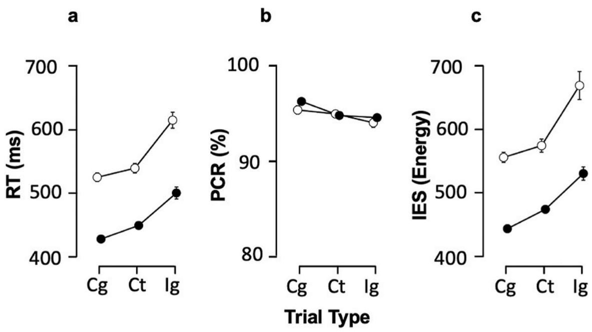

Fig. 2. Group comparison. (a) Reaction times (RT in ms), (b) Percentage of Correct Responses (PCR in %), and (c) Inverse Efficiency Score (IES = RT/PCR in Energy Units, shown for the three trial types (Cg, congruent; Ct, neutral; Ig, incongruent). Filled circles represent mean values for high L2 proficient subjects; Open circles represent mean values for low L2 proficient subjects. Vertical bars represent standard errors.

proficiency interacted significantly with session ($F_{(1,143)} = 6.685$; p = .011; $\eta_p^2 = 0.045$), and was part of a 4-factor interaction including trial type, linguistic context and sex ($F_{(1,282)} = 4.303$; p = .014; $\eta_p^2 = 0.03$). A deeper analysis indicated that PCR varied in a complex manner, increasing or decreasing depending on particular combinations of the 4 factors.

3.4.4. Inverse Efficiency Score (IES)

From these analyzes, it appeared that RT (speed) or PCR (accuracy), taken separately, did not provide a coherent description of behavioral performance, especially regarding whether or not, high L2p improved L1 performance. We then considered the IES which integrates both measures (see Methods). As expected from the pattern of changes just described for RT and PCR, IES (RT/PCR) overall followed the trend of RT pattern (Fig. 2). IES was indeed strongly reduced for all trial types in high L2p participants, compared to low L2p subjects. Statistical analysis showed significant main effects of trial type ($F_{(2,286)} = 86.041$; $p < .001$; $\eta_p^2 = 0.376$), linguistic context ($F_{(1,143)} = 5.666$; p = .019; $\eta_p^2 = 0.038$), session ($F_{(1,143)} = 34.34$; $p < .001$; $\eta_p^2 = 0.194$) and most importantly L2p ($F_{(1,143)} = 15.251$; $p < .001$; $\eta_p^2 = 0.096$). In addition, various 2 factor interactions were observed, namely between session * L2p (p = .003), linguistic context * sex (p = .057), trial type * linguistic context (p = .020), trial type * session ($p < .001$), as well as a 3-factor interaction trial type * linguistic context * L2p (p = .002).

In the following paragraphs of the results, we will use IES (instead of RT) for the following two reasons. First, as stated in the Methods section, a score that integrates both speed and accuracy is more informative about behavioral performance and the cognitive effort deployed to deal with conflict resolution. Second, although PCR did not show group differences at the global level, deeper analyses showed variations that made IES more sensitive than RT, though the differences did not drastically change the main conclusions of the study.

3.4.5. Socio-economic status (SES)

Before going further, we address here the contribution of SES to the observed L2 proficiency effects, as the two factors covaried. To this end, we took SES scores as a covariate, and found that these scores were never correlated with our behavioral measures (RT, PCR or IES; $p > .1$). We noted however that when SES scores were taken as a covariate, the effects of the other factors (linguistic context, social context, sex, L2p) became less or even non-significant, in particular the L2 proficiency (e.g., for IES as the dependent variable, p = .071). The absence of SES effect suggests that improved L1 performance in high L2 proficient participants is likely due to their higher mastery of L2, rather than to their favorable social-economic status (see Discussion).

3.5. Bilingual cognitive advantage: the key role of linguistic context

To test our first hypothesis, which predicts that high L2 proficiency will reduce Stroop interference (SI), we compared SI for Arabic words across the two groups of participants (high vs. low L2 proficiency). In favor of our prediction, SI was drastically reduced in high L2p (vs. low L2p) subjects. However, such an advantage was found only in single language Stroop block, not in mixed language block (Fig. 3a). Indeed, analysis of SI scores using repeated measures ANOVA with linguistic context (single, mixed) and session (first, second) as within subject factors, and L2p (low, high) and sex as between subject factors, revealed a modest main effect of L2p ($F_{(1,141)} = 3.663$; p = .058; $\eta_p^2 = 0.025$), but a significant main effect of linguistic context ($F_{(1,141)} = 7.765$; p = .006; $\eta_p^2 = 0.052$), and a significant interaction between the two factors (linguistic context * L2p; $F_{(1,141)} = 10.439$; p = .002; $\eta_p^2 = 0.069$). As illustrated in Fig. 3, these differences were due to a sharp decrease of SI in high L2p group, observed under the single language condition. Interestingly, the lack of a group difference under mixed language condition was due to improved performance (reduced SI) in low L2p participants, who reached the level of high L2p subjects. Thus, challenging linguistic context benefited low L2p participants, with no effect on high L2p group, possibly due to a ceiling effect (but see Discussion). In addition, this analysis showed a main effect of session ($F_{(1,141)} = 4.401$; p = .038; $\eta_p^2 = 0.030$), but no effect of SES scores taken as a covariate (p = .626).

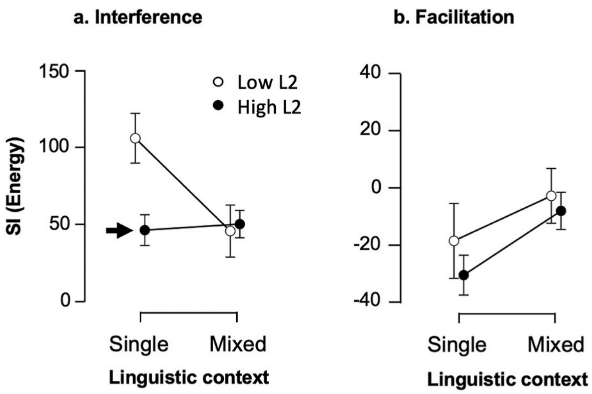

Fig. 3. Effect of L2 proficiency. (a) Stroop interference (SI = IES incongruent – IES neutral) for Arabic words are shown for low and high L2 proficient groups. Note the sharp reduction of SI (arrow) associated with high L2 proficiency, under single language context only. (b) Stroop facilitation (SF = IES congruent – IES neutral).

Stroop facilitation

Although RTs for congruent trials were shorter in highly proficient bilinguals, analysis of Stroop facilitation (Congruent – Control) revealed no significant effect of L2p whether using RT ($p = .468$) or IES ($p = .275$) as the dependent variable (Fig. 3b).

3.6. Social facilitation of bilingual cognitive advantage

The next important question was whether mere presence modulated performance differentially depending on the level of L2 proficiency. To address this issue, we compared SI across experimental sub-groups where subjects were tested in the Alone condition, then in the Presence condition. A repeated measures ANOVA, with linguistic context (single, mixed) and social context (alone, presence) as within subject factors, and L2p (low, high) and sex (female, male) as between subject factors, revealed a significant main effect of linguistic context on SI (F [1,67] = 6.891; $p = .011$; $\eta_p^2 = 0.093$), but no main effect of social context ($p = .157$), nor of sex ($p = .48$). However, a 3-factor interaction social context * linguistic context * L2p tended to reach significance ($F_{(1,67)} = 3.242$; $p = .076$; $\eta_p^2 = 0.046$), and most importantly, there was a significant 4-factor interaction social context * linguistic context * L2p * sex ($F_{(1,67)} = 5.263$; $p = .025$; $\eta_p^2 = 0.073$). This effect was due to a further reduction of SI in high L2p participants under social presence (social facilitation, Fig. 4a), selectively in the single language condition ($F_{(1,67)} = 10.589$; $p = .003$), not in the mixed language condition ($p = .992$; Fig. 4b). In low L2p group, social presence had no effect, irrespective of the language condition (Fig. 4a and b).

3.7. Sex-related effects

When the data from all participants were analyzed, sex did not appear to have any significant effect on SI, whether as a main factor or a in interaction with other factors ($p > .1$). However, as just described, in the experimental groups where social context was manipulated, sex was part of a significant 4-factor interaction. To interpret this interaction, the data were further analyzed separately for females and males, and the results are illustrated in Fig. 5.

In female participants, the analysis showed a highly significant 3-factor interaction between social context, linguistic context, and L2p (F [1,33] = 7.945; $p = .008$; $\eta_p^2 = 0.194$). Note that the effect size increased sharply from 7.3% to 19.4%. Post-hoc analysis showed a significant effect in high (but not low) L2p females, under single language context (F [1,33] = 10.955; $p = .004$; Fig. 5a). Under the mixed language condition, social context had no effect whether in low ($p = .355$), or high ($p = .684$) proficient females (Fig. 5b).

In male participants, social context also affected SI, but under mixed language condition (instead of single language condition, Fig. 5c), and in a different way. As illustrated in Fig. 5d, SI increased in high L2p males and decreased in low L2p males under the Alone condition ($p = .043$), but did not differ across the two groups under social presence ($p = .855$). Comparison of SI across the two social conditions in high L2p participants showed a tendency for a decrease under social presence ($p = .065$), suggesting a weak social facilitation effect in high L2p subjects, whereas social isolation impaired their performance ($p = .043$).

3.8. Control experiment: assessment of the re-test effect

As the Presence condition systematically followed the Alone condition in the experimental groups, improved L1 performance in high L2p subjects may have resulted from task repetition (i.e., practice or re-test effect). To address this issue, we compared SI in control sub-groups, where participants were administered the Stroop test under the Alone condition twice, across the first and second session. A repeated measures ANOVA with linguistic context (single, mixed) and session (first, second) as within subject factors, and L2p (low, high) and sex (female, male) as between subject factors revealed a nearly significant effect of linguistic context ($F_{(1,70)} = 3.699$; $p = .059$; $\eta_p^2 = 0.050$), a significant interaction between linguistic context and L2p ($F_{(1,70)} = 5.290$; $p = .024$; $\eta_p^2 = 0.070$), and a main effect of sex ($F_{(1,70)} = 5.254$; $p = .025$; $\eta_p^2 = 0.070$). However, the session (i.e., task repetition) had no main effect ($p = .081$), nor significant interactions with any of the other factors ($p > .092$). These results suggest that, although participants improved their performance with practice, especially in low L2p group, this does not explain the observed effects of mere social presence, which

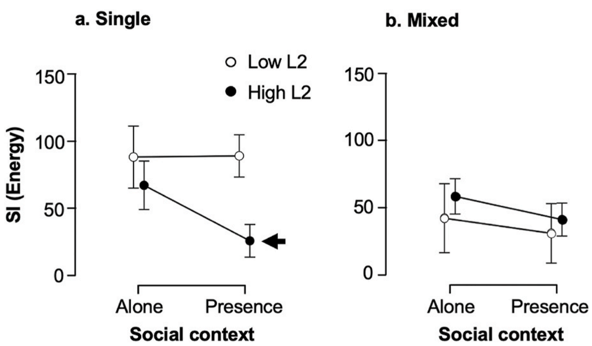

Fig. 4. Modulation by social context. Stroop interference (SI) is shown for Arabic words presented in a single (a) or mixed (b) language blocks, for high and low L2 proficient groups, under two social conditions (Alone, Presence). Note the sharp decrease of SI (arrow) under social presence, in the single language block.

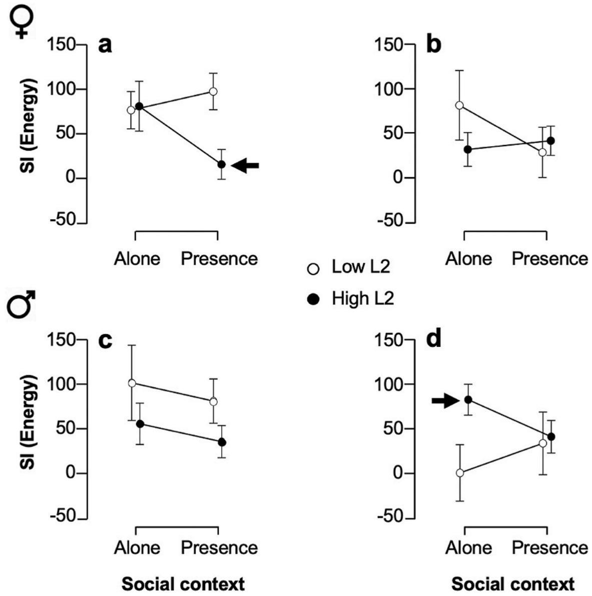

Fig. 5. Sex-related effects on Stroop interference. Interaction L2 proficiency * linguistic context * social context in female (a, b) and male (c, d) participants. Note the social facilitation in high L2 females under the single language block (a, arrow), and the impairment due to social isolation in high L2 males under the mixed language block (d, arrow).

occurred in high L2 group as described above.

4. Discussion

Using the Stroop task, we have shown that Stroop interference during processing of L1 was largely reduced in high L2 proficient Arabic-French bilinguals, supporting the hypothesis of a bilingual cognitive advantage, i.e., higher cognitive capacities for resolving conflict. However, this cognitive advantage was found to depend on multiple factors, namely linguistic context, as it was observed under single-language, but not mixed-language context. Furthermore, we have demonstrated, for the first time, a social facilitation effect on cognitive control of language processes, which occurred in interaction with linguistic context and sex: under social presence, high L2 proficient females outperformed their low L2 proficient counterparts, but only under monolingual context. Thus, while the present results support the existence of a bilingual advantage, they further show that its behavioral manifestation depends on a complex and dynamic interplay between multiple factors, including linguistic context, social context and sex. We will discuss these results to highlight their potential contribution to a new look at the debate on the cognitive benefits of bilingualism, taking into account socio-cultural environment.

A complex linguistic environment in Morocco

The linguistic environment in Morocco is rich and rather complex. Literary Arabic (LA) is the official language of the country and is used in the media, administration, education and official communication, as well as religious practice. It is learned at school, and although mastered by literate people, it is rarely used in daily interactions. The second official language is Tamazight (the Berber language), an Afro-Asian language spoken by a significant proportion of the population for whom it is the native language. The Spoken Arabic (SA, Darija), which is mastered by nearly all Moroccans, is a mixture of LA and Tamazight [53,54], and is considered by linguists as the native language for the majority of the population. In addition to these national languages, and due to the colonial heritage, French is widely used in Morocco. It is learned as L2 in primary school and is extensively used in education and the media. Spanish is also present in the North region, while English is more and more used in education and social media. In terms of daily interactional use, SA is by far the language most widely and intensively used by all Moroccans.

A key aspect to consider in this discussion is the linguistic mode used most frequently [55]. If we refer to the adaptive control model [56], which identified three linguistic modes (single-language context, dual-language context and dense-switching context), the most dominant mode in Morocco is code-switching between SA and French [57–59]. Consistent with these previous studies, our participants reported to code-switch between spoken Arabic and French in 23–25% of their non-academic interactions. Taken together with L2 scores presented in the Results section, linguistic experience and language daily use strengthen the contrast between high and low L2 proficient groups of our study in terms of their bilingual experiences. In one group (high L2, MS students), the bilingual experience was characterized by early age of L2 acquisition, long duration of exposure including three years at the university with exclusive use of French in teaching. In the other (low L2, LS students), the bilingual experience was characterized by a late age of acquisition, a limited duration of exposure to French, including three years at the university with exclusive teaching in Arabic.

Bilingual advantage in Arabic-French speakers: comparison to previous studies

Based on the linguistic context described above, and on current models and theories on bilingualism [56,60,61], we consider that the bilingual experience in our high L2 proficient speakers has potentially led to higher cognitive control capacities, compared to low L2 proficient participants. This cognitive advantage potentially provided the former with greater executive resources for resolving conflict at low cost, as indicated by reduced Stroop interference. This finding is in line with previous studies which have already shown that the more bilinguals master their second language, the better they performed on their native language, a conclusion reached for various cultures and language pairs such as Arabic-Hebrew [48], Spanish-English [47], French-English [62], and Chinese-English [46]. Our results extend this conclusion to Arabic-French bilinguals in a North African culture, and bring additional evidence in favor of the claim that the more bilinguals use and master the second language, the greater their cognitive control capacities when processing their native language. By comparing groups of bilinguals who differ mainly in their level of L2 mastery, rather than contrasting bilinguals with monolinguals, and in non-immigrant speakers, this study strengthens the bilingual advantage hypothesis.

SES may not account for the reported advantage

One critical confounding factor is the participants' socio-economic status (SES), namely because high degree of bilingualism is often associated with higher SES which comes with a cognitive advantage at least in children [63]. In the present study, SES and L2 proficiency were indeed positively correlated, but SES measures were never correlated with any of the performance variables (RT, PCR, IES), nor affected by the factors controlled in the experiment (linguistic or social context, sex, L2 proficiency). Our conclusion is that SES did not contribute in any significant way to the bilingual advantage reported in the present study. Other studies have reached a similar conclusion on the ground that bilingual advantage can be observed in adults with very low SES [64], or that, in children, SES and bilingualism contribute to the cognitive advantage but independently one from another [65]. As noted by Paap [18], SES cognitive advantage, present in children, does not seem to persist in young adults, namely university students, such as the population included in the present study.

Bilingual cognitive advantage depends on linguistic context

Linguistic context and the everyday use of the spoken languages modulate the demands on executive control (see [24,25]), as theorized by Green [55,56]. Expectedly, we found linguistic context to be by far the most important factor, which not only affected the behavioral measures systematically as a main factor, but determined language group differences through interactions with L2 proficiency, or other factors. One of the key findings is that bilingual advantage was apparent selectively under single language condition, not when L1 words were presented in a mixed language condition. Sabourin and Vinerte [62] have stressed the importance of using mixed language blocks, which are more likely to mimic real life situations where two (or more) languages co-exist. The lack of group differences in the mixed language context in the present study is not to be taken as evidence for the absence of a cognitive advantage. Indeed, mixed language context selectively improved cognitive control in low L2 proficient subjects, who reached a similar level of performance than high L2 participants. One way to intepret this selective improvement of performance in low L2p (vs high L2p) participants might be that high L2p subjects have reached their ceiling performance. However, tested under social presence, highly proficient bilinguals were able to improve their performance beyond the suspected ceiling level (see Fig. 4). A more plausible explanation would be that bi- or multilingual context (as in real life), is more challenging, possibly leading to a higher level of general executive resources deployed to accomplish the task. Other studies have reported a similar phenomenon of improved cognitive control with task difficulty. For example, Wu and Thierry [66] found increased response accuracy with task difficulty in English-Welsh bilinguals, whereas Martin-Rhee and Bialystok [67] found bilingual advantage in young adults only when the task was difficult. Also, Costa et al. [68] found bilingual advantage only when conflict monitoring was high. Sabourin and Vinerte [62] reported a somewhat different result in English-French bilinguals, as group differences were made apparent by the mixed language condition in their study, whereas we report the opposite pattern. Nevertheless, both studies converge on the conclusion that cognitive control in bilinguals depends on linguistic context. In line with these previous studies, we conclude that challenging linguistic environment facilitates executive control in bilinguals, and improves performance. Our hypothesis is that increased difficulty requires greater attentional focus on the task at hand and reduces interference, in line with the load theory put forward by Lavie [69].

Social facilitation of cognitive advantage: an integrated view of executive attention

Social context is among the key factors that contribute to bilingual experience (see Introduction). In the present study, social context is approached from the general standpoint of mere presence, i.e., awareness that another social agent is present in the immediate environment, even without any intention to communicate or interact. The social facilitation paradigm, which has long been used in social psychology, has the advantage of addressing the role of social context in modulating cognitive control without introducing the more complex processes of inter-individual communication. Social facilitation has been reported for a variety of tasks and behaviors (e.g. Refs. [34,70]), but not for language processes. Our results show that mere presence facilitates behavioral performance in highly proficient bilinguals. However, contrary to our expectation, mere presence did not directly affect Stroop interference, suggesting that social context taken alone may not play a key role in the expression of bilingual advantage. Alternatively, this lack of a main effect may indicate that social context had an indirect, more complex role through modulation of other factors. The results support this possibility, as social context's effect on performance was found within a multi-factor interaction involving L2 proficiency, linguistic context and sex. This multi-factorial interaction indicates that bilingual cognitive advantage should be considered within the complexity of social and cultural environment.

Finally, if bilingual advantage is taken within the executive attention hypothesis, our results bring together the two phenomena - bilingual advantage and social facilitation - in an integrated view of management of attentional resources. On the one hand, highly proficient bilinguals appear to benefit from a cumulative effect of bilingual advantage and social facilitation. On the other hand, as discussed above, not only that low bilingualism comes with weak cognitive control capacities, but also with low sensitivity to social context. Consequently, subjects fail to monitor the social agent, leaving more resources for automatic word reading processes. In other words, increased interference reflects weaker capacities to filter out distracting information, possibly due to weak social cognitive abilities.

Bilingual advantage, sex differences and age group

We have conservatively used the term "sex", rather than gender, to refer to the distinction between male and female participants of our study. However, sex-related effects may also be taken from a more global perspective which includes the social implications of being male or female. The reported sex-related phenomena may indeed be viewed as gender effects. This being said, moderation of bilingual cognitive advantage by social and linguistic context varied between male and female participants. In particular, as noted in the Results section, the effect size of the multi-factor interaction has increased sharply from 7.3% when males and females were grouped together, to 19.4% in females analyzed separately. We interpret these differences between females and males in relation with their social cognitive differences, as it is relatively well established that women and men generally differ in terms of socio-emotional behavior (for review see Ref. [71]). For example, women exhibit higher empathy, and show greater scores on perspective taking tests than men, and it was recently shown that bilingualism improves perspective taking abilities in a sex-dependent manner [72]. Other studies have reported that bilingualism promotes socialization by enhancing social cognition [73,74]; for recent reviews see Refs. [71, 75]). Taken within this socialization view, our interpretation of sex-dependent facilitation of cognitive control is that, highly proficient bilingual females were more sensitive to social presence than males. In favor of this interpretation, we found higher scores on the Liebowitz Social Anxiety Scale in females, compared to males. Overall, it seems as if increased sensitivity to social context in highly bilingual females led to allocation of greater attentional resources to the monitoring of the audience. As a result, females focused more on the task at hand, and less on the automatic word reading tendency (reduced interference). By contrast, males seemed to allocate less attention to social presence, presumably due to their lower sensitivity to social context. This may have led to more distraction from word reading, requiring more executive resources to resolve conflict.

Finally, bilingual advantage has been suggested to vary across the life span as it was reported more reliably in children and older adults, than in young adults (for reviews see e.g. Refs. [2,3,18,76]). The intuitive explanation was that advantages on executive functions are difficult to detect when these functions are at their peak, a phenomenon known as the ceiling effect [3,76]. The fact that our results show a large bilingual advantage in this group age (university students, 20–24 years old) under specific social and linguistic conditions, strengthens the need to take into account the context when assessing language processes.

Bilingual advantage: a multifactor moderation hypothesis

To illustrate how the complex interactions between the controlled factors may affect cognitive control, we followed the approach of

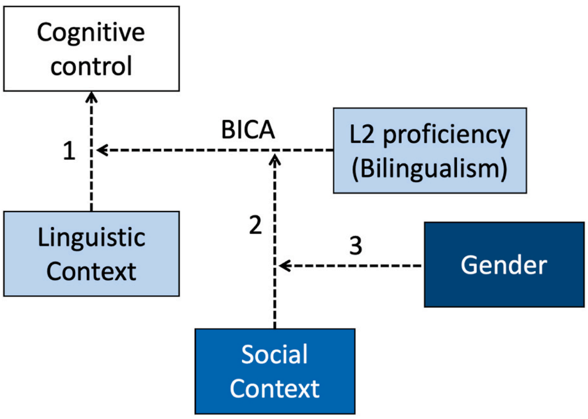

Fig. 6. Hypothetical multifactor moderation model of bilingual advantage. Arrows summarize the results of this study. The effect of linguistic context ([1]) on cognitive control is moderated by L2 proficiency (BICA). The effect of the latter is moderated, in turn, by social context ([2]) and gender ([3]). Cognitive advantage, assessed as the positive effect of bilingualism on cognitive control, was enhanced by mere social presence in a gender-dependent manner.

the moderation model [77] to suggest a hypothetical functional model (Fig. 6). Moderation corresponds to interactions between variables and implies that the effect of a variable Y (e.g., linguistic context) on a variable X (dependent variable, e.g., Stroop interference) is different for different states of a third variable Z (e.g., L2 proficiency). As we have shown, Stroop interference was directly modulated by linguistic context (reduced interference), but the effect depended on L2 proficiency. Thus, one can state that L2 proficiency (i.e., bilingualism, Fig. 6), moderates the effect of linguistic context on cognitive control. In turn, this moderation of cognitive control by bilingualism depended on social context and sex. Neither of these factors affected cognitive control directly, or through interactions with linguistic context or L2 proficiency separately. Rather, social context and sex appeared to operate at a higher level of this multifactorial moderation chain. Cognitive advantage, assessed as the positive effect of bilingualism on cognitive control, was enhanced by social presence in females (social facilitation), but specifically in a monolingual context, i.e., when linguistic demands were low. Overall, these findings suggest that the behavioral expression of bilingual advantages is embedded in a complex interaction between at least 3 factors: linguistic context, social context, and sex. It is the dynamic interplay between these factors, and most likely other socio-cultural factors not controlled in this study, that will ultimately determine the behavioral outcome.

Limitations

There are some limitations that need to be taken into account. Perhaps the most important issue relates to bilingualism as opposed to multilingualism. Our study focused on bilingualism and how mastering French as L2 affected cognitive control on spoken Arabic as L1. Yet, we are aware that most of our participants are multilingual to various degrees, and that the more languages they master, the more they may develop cognitive control capacities [78]. In this respect, it would have been instructive to assess the full linguistic competences of the participants, and the degree of mastery and use of each language they have acquired. In particular, it would be useful to address how the level of mastery of LA affects cognitive control on SA, depending on whether it is intensively used (as in LS), or not (as in MS). Likewise, the contribution of Tamazight (another native language of many Moroccans) to the development of cognitive control would be important to examine, in parallel to spoken Arabic. These issues remain to be addressed in the future.

5. Conclusions and future directions

The present study opens new avenues for advancing the currently deadlocked debate on the bilingual cognitive advantage. We demonstrate that, although bilingualism comes with a cognitive advantage, its expression is adaptively moderated by social context and its interactions with linguistic context and sex. Importantly, we show that social context is a key factor and extend the social facilitation phenomenon to language, the most elaborate function of the human brain. This study also extends the bilingual advantage hypothesis to Arabic-French, non-immigrant bilinguals living in a non-western culture. Under these conditions, we found a female social and cognitive advantage of bilingualism, whereby high L2 proficiency boosts both cognitive control and sensitivity to social context. Given that language is fundamentally rooted in social context, we believe that the bilingual cognitive advantage debate may overcome the current impasse by combining psycholinguistic and social psychology approaches in future studies.

Author contribution statement

Amine Bennani; Driss Boussaoud: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper. Abdessadek El Ahmadi: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper. Ahmed Channouf; Mohammed Benzagmout; Said Boujraf: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no competing interests.

Declaration of competing interest

None.

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