Psychological Research (2013) 77:728–737
DOI 10.1007/s00426-012-0466-4

ORIGINAL ARTICLE

Bilingualism and the increased attentional blink effect: evidence that the difference between bilinguals and monolinguals generalizes to different levels of second language proficiency

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Received: 20 April 2012 / Accepted: 12 November 2012 / Published online: 30 November 2012

Abstract The attentional blink task involves rapid serial presentation of visual stimuli, two of which the participants have to report. The usual finding is that participants are impaired at reporting the second target if it appears in close temporal proximity to the first target. Previous research has shown that the effect is stronger in bilinguals than monolinguals. We investigated whether the difference between monolinguals and proficient bilinguals can be extended to bilinguals of different proficiency levels. Therefore, we replicated the paradigm in a large sample of Hindi–English bilinguals with different proficiency levels of English, as measured with a validated vocabulary test. We additionally measured the participants' intelligence with the raven progressive matrices. We found that the size of the attentional blink effect correlates with the degree of second language proficiency and not with the degree of intelligence. This indicates that research on executive control functions can be done with bilinguals of different proficiency levels. Our results are also in line with recent findings showing that the attentional blink effect is not primarily due to limited processing resources.

Introduction

Due to increased mobility bilingualism has become a norm, particularly in groups of people that are not economically or culturally dominant (Myers-Scotton, 2005). For economic, scientific, and cultural reasons a large number of individuals acquire and use knowledge of more than one language in their life. Independent of the way in which they became bilingual (e.g., through birth in a multilingual family, by education, occupation or immigration) the experience with more than one language is likely to have a significant impact on their cognitive functioning (Bialystok, Craik, Green, & Gollan, 2009).

Evidence from behavioral (Brysbaert & Dijkstra, 2006; Francis, 1999; Grainger, 1993; Kroll & de Groot, 1997) and imaging studies (Marian, Spivey, & Hirsch, 2003; Rodriguez-Fornells et al., 2005) has indicated that the languages of a bilingual are not separated but are jointly activated during comprehension and production. This means that active control mechanisms are needed to avoid interference from the other language when one is being used. Several hypotheses have been proposed (Costa, 2005; Green, 1998; La Heij, 2005), which all agree on the assumption that bilinguals make use of some form of inhibition of the non-target language. Evidence in favor of the use of active inhibition comes from studies in language production, in which bilingual speakers are asked to switch between naming objects in their first and second language (L1 and L2, respectively). A typical finding in these studies is that the switching costs from L2 to L1 are larger than the other way around (Meuter & Allport, 1999), arguably because bilinguals must overcome stronger inhibition of L1 when speaking L2 than vice versa.

The continuous use of language control in bilinguals has been shown to have an impact on other general executive control functions. Indeed, researchers have found that bilinguals are at an advantage when it comes to using executive control functions (Bialystok, 1999, 2001; Bialystok & Martin, 2004; Craik & Bialystok, 2006). Bialystok (1999)

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found that bilingual children outperformed their monolingual peers in a dimensional change card sorting task, which required the participants to shift the criterion of classification from color to shape. Bialystok, Craik, Klein and Viswanathan (2004) compared the performances of several groups of monolinguals and bilinguals from different ages on the Simon Task, a task that requires participants to inhibit a prepotent response tendency. The authors found that bilinguals again outperformed monolinguals. The advantage was present for all age groups (see, however, Craik & Bialystok, 2006; Bialystok, Craik, & Ruocco, 2006 for findings suggesting that more research is needed to unequivocally show a behavioral difference between monolinguals and bilinguals at all ages). Bialystok and Shapero (2005) compared the performance of 6-year-old bilingual and monolingual children on the children's embedded figures test; they found that bilingual children needed less cuing and made fewer errors while identifying the image embedded in the probe figures.

All in all, bilinguals have been shown to have an advantage over monolinguals in a variety of tasks involving inhibition of irrelevant information or pre-emptive responses.

Colzato et al. (2008) investigated the nature of the inhibitory processes in bilingual language control by testing bilinguals and monolinguals on three different tasks, which arguably tapped into different mechanisms. They used the stop-signal task as a test of direct action inhibition, the inhibition of return task as a test of attention-based inhibition, and the attentional blink task as a test of reactive inhibition. The authors found that bilinguals and monolinguals performed comparably on the stop-signal task, but differed on the other two tasks. The difference between monolinguals and bilinguals on the inhibition of return task was difficult to interpret conclusively in terms of the mechanism of inhibition involved, leaving only the third task with straightforward results, the attentional blink task.

The attentional blink (AB) task involves a rapid serial visual presentation (RSVP) of stimuli (Raymond, Shapiro, & Arnell, 1992). Participants are asked to identify two targets presented at varying lags. If the first target (T1) is reported correctly, the second target (T2) usually has a high probability of being missed if it occurs between 100 and 500 ms after the first target. Several theoretical explanations have been offered to account for this marked deficiency in T2 reporting (for reviews, see Dux & Marois, 2009; Martens & Wyble, 2010). For example, the structural bottleneck explanation assumes that the processing and consolidation of T1 occupies attentional resources, leaving too few resources for the processing and consolidation of T2 for it to be reported. Although capacity limitations are likely to be involved in the AB effect (e.g., Dell-Acqua, Dux, Wybe, & Joliceur, 2012), they do not seem to be the most important factor, as participants can report more than one targets without difficulty if they are presented in sequence (a finding first reported by Di Lollo, Kawahara, Ghorashi, & Enns, 2005).

The presence of distractors between the two targets seems to be responsible for the blink in attention. Participants need to shield T1 against the impact of the distractors and this seems to be important in the AB phenomenon. Other findings (Olivers & Nieuwenhuis, 2005; Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006) also indicate that there is a trade-off between the amount of resources allocated to the processing of T1 and the performance on T2. Taking these findings together, Colzato et al. (2008) argued that AB reflects the efficiency of noise suppression, by virtue of local reactive inhibition. Hence, the magnitude of AB shown by an individual depends on the amount of resources spent in providing support for the to-be-selected stimulus and the amount of reactive inhibition applied to the competing distractors. The authors concluded that as bilinguals have extended practice in strengthening target language representations and/or suppressing non-target language representations, they should experience more difficulties in reporting T2 in the attentional blink task. That is, they should exhibit a larger attentional blink as compared to their monolingual counterparts. Performance of the bilinguals and monolinguals on the attentional blink task confirmed the hypothesis. On the basis of this finding, Colzato et al. (2008) concluded that the bilingual advantage in executive functions should be viewed in a different light, not as an advantage overall but as a general improvement in selecting goal-relevant information and suppressing goal-irrelevant information.

All studies investigating the consequences of bilingualism for executive control functions tasks thus far have compared the performance of monolinguals and bilinguals. However, being a bilingual is not an absolute, all-or-none status. Decades of research have identified variables that may be used to divide bilinguals into various groups based on quantifiable criteria. Important variables include the age of acquisition of the second language and the bilinguals' proficiency in both languages (Chee, Hon, Lee, & Soon, 2001; Perani et al. 1998; Zied et al. 2004). Therefore, it would be interesting to examine whether a difference observed between monolinguals and bilinguals can be extended to bilinguals of different proficiency levels. Is the transition from monolingual to bilingual a gradual process, so that we will observe a monotonic relationship between the size of the AB effect and the proficient level of the bilingual? Or does the AB effect suddenly increase at a low level of proficiency, when control processes start to kick in, so that we will observe an equally large AB effect for all bilinguals but the ones at the very low end of the proficiency range?

Finding a difference between low and high proficiency bilinguals would further be interesting, because it would open the research topic of control processes in bilinguals to a much larger population. A problem with the current situation is that one can only do "monolingual" research in native, English-speaking countries or in non-student populations. This effectively rules out research in many countries, such as India and Belgium, where knowledge of a second language is common from a certain educational level on. Having to compare monolinguals and bilinguals from different countries entails the danger of culture-specific confounds that may obscure the interpretation of the results.

Some evidence that differences in L2 proficiency may have an effect similar to that observed between monolinguals and bilinguals was reported by Dash and Kar (2012). These authors examined the effect of L2 proficiency among Hindi–English bilingual adults on an attention network task (which is a combination of a flanker and a cuing task). They observed faster responses for highly proficient bilinguals both on congruent and incongruent trials and an additional advantage with respect to the orienting of attention.

The AB effect is an ideal task for the comparison of various L2 proficiency levels, because it puts highly proficient bilinguals at a disadvantage. In addition, the disadvantage is rather counter-intuitive. On the basis of face validity, one might expect that bilinguals, having better inhibition capacities than monolinguals, would show a smaller AB effect than monolinguals (i.e., opposite to Colzato et al.'s finding). Furthermore, the AB effect has been shown to be unaffected by the participants' intelligence, as measured with Raven's Progressive Matrices (Martens & Johnson, 2009; see also Colzato, Spapé, Pannebakker, & Hommel, 2007). A likely correlate of L2 proficiency is intelligence (participants who are not good at L2 may be of lower intelligence than persons who are good at it). Therefore, the interpretation of the findings is easier if one can use a task that is independent of intelligence.

To look at the effect of L2 proficiency, one also needs a reliable and valid estimate of language proficiency. All too often, researchers simply ask their participants to rate their proficiency level on a Likert scale. This is likely to be too coarse a measure, which additionally is open to response biases. For a long time, the only alternative was a commercial proficiency test. However, Lemhoefer and Broersma (2012) recently published a free language proficiency test, LexTALE, which performs very well on various criteria. The test consists of 40 English words of various difficulty and 20 non-words, from which the participants have to indicate the words they know.

In the present study, we sought to replicate the pattern of results published by Colzato et al. (2008) with bilinguals of different proficiency levels. To increase our chances of finding an effect, we ran the study on a large number of participants ($N = 132$) living in comparable socio-economic status and having similar educational backgrounds, but differing considerably in L2 proficiency as measured with LexTALE. We additionally administered the Raven's progressive matrices IQ test, to make sure that any effect we found was not simply a confound of (fluid) intelligence. Finally, we increased the number of trials in the AB task, to get more stable estimates of the AB effect at the individual level.

Method

Participants

A total number of 132 young adults (mean age 18.5 years, range 17–24 years) gave informed consent and participated in the study. They were paid. All participants had either normal or corrected to normal vision. The sample comprised of Hindi–English bilinguals living in Allahabad, India. All participants had learned both languages from childhood as to their needs (in particular the level of English instructed at the primary and secondary school they went to). All participants belonged to the first year of their undergraduate study where instruction was in English. They were new to the type of study being conducted. Instructions were given both in L1 and L2. All participants had done their final exams of secondary education in English. All came from similar, middle-class socio-economic background and reflected no major differences in cultural environment.

Apparatus and stimuli

The participants were tested with a laptop PC (Dell with a 15.1-in. monitor). Responses were registered by pressing the required keys in response to the questions of the standard AB task. The stimuli were 16 English letters written in Times New Roman font, size 14 and projected in RSVP format at the centre of the screen.

Procedure

All participants were first asked to fill in the three paper-and-pencil tests. First, they completed the LexTALE test of L2 proficiency (Lemhoefer & Broersma, 2012). This is a test of English vocabulary, in which participants have to indicate which English words they know. There are 40 existing words in the list and 20 word-like non-word lures, which make it possible to correct the performance for any tendency the participants may have to select more "words" than they know).

The second test was the Raven's progressive matrices (Raven, Raven, & Court, 1998). This is a test of non-verbal, fluid intelligence. On each trial, participants are shown eight patterns arranged in a three-by-three matrix and are asked to select the missing ninth stimulus from a sequence of alternatives. Trials progressively become more difficult. Raven's Progressive Matrices is a test of inductive reasoning, which has often been used to match samples on IQ. The test was administered according to the guidelines provided in the manual. In particular, this meant that the participants had to solve as many matrices as they could in 45 min of time.

The final paper-and-pencil test administered was a traditional language background questionnaire. It asked participants about the age of acquisition for the known languages, the amount of use, exposure and mixing of the known languages, and also the manner and environment in which the participants make use of their languages (L1, L2).

After the completion of the paper-and-pencil tasks, the participants were asked to take part in the Attentional Blink experiment. In our version of the AB task (based on Raymond et al., 1992), participants were instructed to look for a white English letter (T1) in an RSVP stream with 14 black distractor letters, and to type in the white letter at the end of the trial. T1 always appeared at Position 7. Participants were also asked to report whether they had seen a black X (T2) after the white letter. This letter could appear at various lags (Positions 8–15). There were 40 T2-present trials per position and 40 T2-absent trials. All letters were presented for 15 ms and ISI was 75 ms. The dependent variables were the accuracy of T1 reporting and the accuracy of T2 detection.

Results

The mean accuracy of T1 reporting was 75.4 % (see below for further analyses related to individual differences). T2 accuracy is traditionally measured for those trials in which T1 was correctly identified (indicated as T2|T1 accuracy). Figure 1 shows the mean T2|T1 accuracy as a function of stimulus position (absent and Pos 8–15, which correspond to lags 1–8) and L2 proficiency (high vs. low, based on the median split). L2 proficiency was defined as the average of the percentage correct answers on the word and non-word trials (i.e., number of words correct/40 × 100 + number of non-words correct/20 × 100)/2; Lemhoefer & Broersma, 2012). The scores of the high proficiency half ranged from 73.5 to 97.5, whereas those of the low proficiency half ranged from 48.0 to 73.5.

Figure 1 shows that we were successful in replicating the standard AB finding: Participants were markedly deficient in reporting T2 at lag 2 (Pos 9) after which performance gradually improved with increasing lag (the main effect of position was very robust: $F(8, 1040) = 90.3$, MSE = 273.1, $p < 0.001$, $\eta^2 = 0.41$). Also, the performance of the participants was better at the first lag after T1 appearance (Pos 8), which is another standard finding of the AB phenomenon (lag 1 sparing).

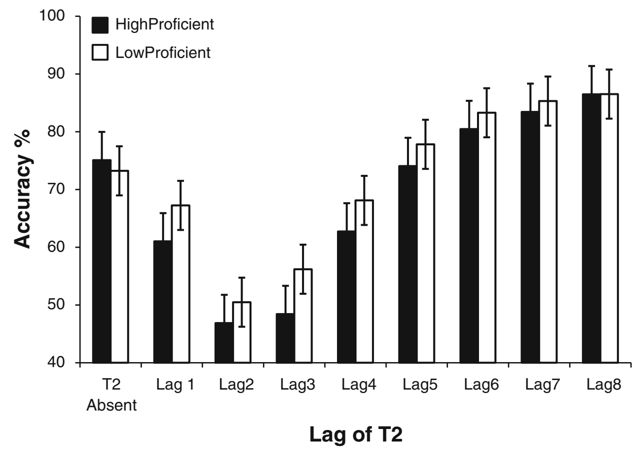

Fig. 1 Accuracy of T2 detection as a function of T2 position (absent, positions 8–15) and L2 proficiency of the participants (high vs. low, based on median split). Accuracies are based on those trials in which T1 (always presented at Pos 7) was correctly identified

More importantly, Fig. 1 suggests that we were successful in replicating Colzato et al. (2008), because the AB effect looks stronger for the highly proficient bilinguals than for the less proficient bilinguals. Although there was no overall main effect of proficiency in the omnibus analysis of variance [$F(1, 130) = 2,75$, MSE = 1,249, $p = 0.11$)] nor a significant interaction between proficiency and lag [$F(8, 1,040) = 1.1$, MSE = 273.1, $p = 0.36$)], there was a significant difference between the two groups when the analysis was limited to positions 8–11 [i.e., lags 1–4; $F(1, 130) = 3.0$, MSE = 4,359, $p < 0.05$, one-tailed].

To examine the effect of L2 proficiency more in detail and to make full use of the power of the design, we used linear regression analysis. We also examined various indices to estimate L2 proficiency. The first measure was the simplest measure proposed by Lemhoefer and Broersma (2012) and also the one used to distinguish the two proficiency groups in Fig. 1. It simply consists of the average percentage correct words and percentage correct non-words. It is a rather crude correction for the tendency to select more words than known to the participants and takes into account that the number of non-word items (20) was only half that of word items (40).

The second measure was *d*-prime (d') based on signal detection analysis. We followed Stanislaw and Todorov (1999) and computed d' in Excel with the equation:

$d' = \text{NORMSINV}(H) - \text{NORMSINV}(F)$

in which H = hit rate (number of correct words/40) and F = false alarm rate (number of incorrectly selected non-words/20). In the few cases where F was 0, it was replaced by 0.5/20, to avoid infinite values. NORMSINV is an Excel function that returns the z value associated with the cumulative standard normal distribution. So, it would return the value −1.96 if H or $F = 0.05$, and +1.96 if H or $F = 0.95$).

Another statistical measure for determining sensitivity in signal detection is A'; this is a non-parametric statistic devised by Pollack and Norman (1964). A' typically ranges from 0.5, which indicates that the signal is indistinguishable from noise, to 1, which corresponds to perfect performance. We again followed Stanislaw and Todorov (1999) and computed A' in Excel.

We correlated the above three measures of L2 proficiency with the size of the AB effect. The latter was defined as the summed T2|T1 score on Pos 13–15 minus the summed T2|T1 score on Pos 9–11. To these predictor variables we also added the Raven progressive matrices performance of the participants and the response bias on LexTALE. The former was defined as the number of trials correctly solved. The response bias was defined as the tendency to try to improve performance either by not selecting words one was not sure of (in order not to select "wrong" words) or by including words one was not sure of in the hope that more of them would turn out to be existing words rather than non-words. In signal detection analysis, the response bias can be measured by β (beta). When the subjects' performance is free from bias, β (beta) will be 0; values less than 0 signify a bias toward saying YES (in our case classifying all stimuli as words) and values more than 0 signify a bias toward saying NO (in our case classifying all stimuli as non-words). The formula we used for calculating β (beta) in Excel was suggested by Stanislaw and Todorov (1999):

$$\beta(\text{beta}) = \text{EXP}((\text{NORMSINV}(F)^2 - \text{NORMSINV}(H)^2)/2)$$

Again 0-values of F were replaced by 0.5, to avoid impossible calculations.

Finally, to be able to decide how specific our findings were for the AB phenomenon, we also ran the analyses on T1 accuracy. According to Colzato et al. (2008) this variable should be correlated more with intelligence than with L2 proficiency.

Table 1 shows the intercorrelations between the different measures. These are based on the scores of all 132 participants. As can be seen, d' correlated most with AB, whereas Raven's correlated most with T1 identification. As could be expected, the various measures of L2 proficiency were highly intercorrelated.

Table 1 Correlations of the various indices of L2 proficiency (as measured by LexTALE) and dependent measures of the attentional blink task

	d'	A'	Ravens	Beta	AB	T1
% correct	0.56**	0.59**	0.20*	0.30**	0.26**	0.07
d'		0.94**	0.09	0.16	0.35**	−0.04
A'			0.05	0.13	0.32**	−0.05
Ravens				0.19*	0.13	0.22*
Beta					0.07	0.01
AB						0.06

d' is parametric measure of L2 proficiency; while A' is a non-parametric index; Ravens indicates performance on the intelligence test (RPM), AB indicates attentional blink magnitude; T1 indicates accuracy of T1 detection

** $p < 0.01$, * $p < 0.05$, $N = 132$

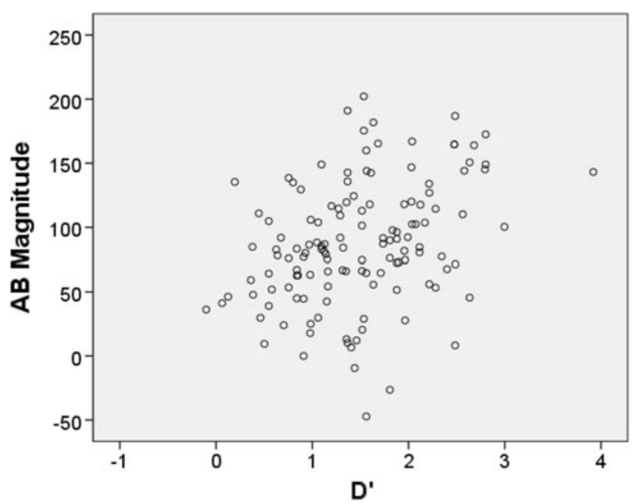

Fig. 2 Correlation between d' as an estimate of L2 proficiency and AB magnitude

Next we ran a forward stepwise regression analysis using %correct, d', A', Ravens, and beta as predictors of AB magnitude. This model starts with the best predictor and adds other variables to the regression model if they make a significant extra contribution. Only the variable was d' was selected ($t(130) = 4.215$, $p < 0.01$, $R^2 = 0.12$). No other variable was included. Figure 2 shows the correlation between d' and AB.

To find out whether the results were specific for AB magnitude, we ran another forward stepwise regression analysis using the same variables as predictors of T1 accuracy. In this analysis, only performance on the Raven's progressive matrices was significant ($t(130) = 2.605$, $p < 0.05$, $R^2 = 0.05$). Figure 3 shows the correlation between Raven's and T1 identification.

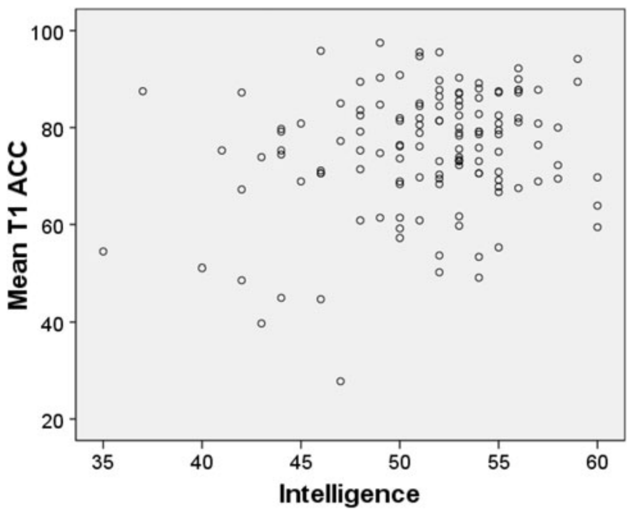

Fig. 3 Correlation between T1 accuracy and intelligence (Raven's Score)

To see whether the Language Background Questionnaire gave extra information, we defined the following variables:

- Age of acquisition of L2 (in years)
- Self-rated proficiency in L2 (on a 7-point Likert scale; average for listening, reading, speaking, writing)
- % time in L2 environment
- Teaching language (language used while they were being taught at primary and secondary school)
- Frequency of mixing (number times they use both L1 and L2, in various situations for e.g. work, home, socially, etc.)

Table 2 shows the correlations between these measures and the magnitude of the AB effect and T1 identification. As can be seen, none of the correlations reached significance. None of the variables was selected either when entered in a forward stepwise regression analysis on AB or T1.

Discussion

In the present study, we sought to investigate whether differences between monolinguals and bilinguals can be extended to differences in L2 proficiency, which would make this type of research possible in countries with widespread bilingualism in the student population, and which additionally might tell us from which proficiency level on an effect starts to appear. To this aim, we tried to replicate a counter-intuitive finding published by Colzato et al. (2008), who observed that bilinguals show a larger AB effect than monolinguals.

Table 2 Correlations of the Language Background and History Questionnaire measures with dependent measures of the attentional blink task

	AoA	SRP	L2 use (%)	TM	FoM
T1	0.025	0.137	0.031	−0.002	0.172
AB	−0.063	0.090	0.096	0.018	0.025

T1, accuracy in T1 detection; AB, magnitude of attentional blink; AoA, age of acquisition; SRP, self-rated proficiency in L2 (% of L2 use); TM, medium of education/teaching; FoM, frequency of mixing

$N = 132$, * $p < 0.05$

First, we were able to replicate the AB effect (Fig. 1) and the fact that it is not influenced by the participants' fluid intelligence as measured with the Raven's progressive matrices test (Table 1). We also observed that T1 performance was influenced by the participant's intelligence, as reported by Colzato et al. (2007). This shows that the AB task we used was valid and that our participants from India performed similar to the Western participants tested before.[1]

More importantly, we were able to show that the difference between bilinguals and monolinguals did extend to differences between bilinguals of different L2 proficiency levels (Table 1), at least if the proficiency was measured with an objective vocabulary test correcting for response bias (Lemhoefer & Broersma, 2012). If participants simply indicated on a questionnaire how proficient they considered themselves and how often they used L2, no significant correlations were found (Table 2). When an objective measure is used, large differences in L2 proficiency were observed in our participants. Indeed, the percentages of accuracy ranged from 48 to 97.5. A score of 48 means that the participant was slightly more inclined to select a non-words as a "known" English word than a word (i.e., was unable to tell English words from non-words in the test). A score of 97.5 means virtually flawless performance. The wide range of proficiency scores agrees with another study we recently ran with Hindi–English bilingual adults (age range 18–25 years; Kar, 2012). In this study too it was found that L2 proficiency across language skills (speaking, understanding, reading and writing) differed markedly and varied as a continuous variable. Importantly, the L2 proficiency is not related to fluid intelligence as measured with the Ravens progressive matrices (Table 1), because it mainly reflects differences in schooling (the importance given to English in primary and secondary school).

It seems reasonable to interpret L2 proficiency as an estimate of the degree of practice in L2 use and, therefore,

[1] The successful replication also suggests that stimulus presentation on a laptop screen is equally good as on a CRT screen if enough trials are presented to the participants.

as an estimate of practice in language control. The linear relationship between L2 proficiency and the size of the AB effect (as shown in Fig. 1) then indicates that monolinguals and highly proficient bilinguals are extremes of a continuum that spans a wide range of practice (and effort). It is not the case that some acquaintance with a second language profoundly changes the AB effect and, hence, the quality of the executive control processes. Only sustained effort seems to do so. This has the benefit that the AB effect can be examined with bilinguals of various proficiency levels. It is not necessary to have pure monolinguals in one condition.

Finally, our findings have implications for the literature on the AB effect as well (see Dux & Marois, 2009; Martens & Wyble, 2010, for reviews). The phenomenon of the post-target processing deficit was first observed by Broadbent and Broadbent (1987), who found that participants were impaired in reporting a second target in an RSVP presentation if the second target appeared within half a second of the first. They explained their results by proposing that at short inter-item intervals the target identification processes interfered with each other (also see Weichselgartner & Sperling, 1987, for a similar finding and interpretation around the same time). The term attentional blink, analogous to blinks of the eye, was introduced by Raymond et al. (1992). They asked participants to identify a single white letter in an RSVP stream of black letters and to detect the presence/absence of a black X appearing after T1. Participants were found to be deficient in detecting the second target if the first target (T1) was identified correctly and the black X appeared within 200–600 ms of the first target.

Another robust finding in the AB paradigm is that participants perform better when the second target appears immediately after the first. This has been replicated over and over again and is known as *lag 1 sparing* (Potter, Chun, Banks, & Muckenhoupt, 1998; Visser, Bischof, & Di Lollo, 1999). The degree of sparing depends on the similarity of T1 and T2 and of the tasks to be performed. The higher the similarity, the more sparing. In the extreme case, when T1 and T2 belong to the same stimulus category and require the same response, the sparing is total and can extend for several trials (i.e., participants are able to report several targets presented in rapid sequence; Di Lollo et al., 2005; Olivers, van der Stigchel, & Hulleman, 2007). For the task introduced by Raymond et al. (1992), lag 1 sparing usually is not complete, as can be seen in Fig. 1 (see also Shapiro, Raymond, & Arnell, 1994).

Several theoretical accounts and computational models have been proposed to explain the findings (for reviews, see Dux & Marois, 2009; Martens & Wyble, 2010). Initially, researchers assumed that AB was the outcome of capacity limitations (Chun & Potter 1995; Ward & Duncan 1996; Joliceur 1998, Jolicoeur 1999; Potter, Staub, O'Connor, 2002; Dux & Harris 2007). These models were governed by the assumption that target processing in RSVP is a two-stage process. In the first stage, an item activates its stored conceptual representations. There is good evidence that this occurs for both T1 and T2. In the second stage, items are consolidated and brought into consciousness for reporting (Martens & Wyble, 2010). This stage is thought to be capacity limited, so that T2 must compete with T1, decreasing the chances that it will be available for report at the end of the trial.

The bottleneck models dominated the theoretical landscape of the AB literature for more than a decade, but recent findings have called them into question. One of these findings is that the AB effect can be attenuated in various, counter-intuitive ways. For example, the AB effect can be made smaller by asking participants to listen to task-irrelevant music or to do a concurrent secondary task (Olivers & Nieuwenhuis 2005; Wierda, van Rijn, Taatgen, & Martens, 2010). Another surprising finding is that some participants show no AB at all (e.g., Dux & Marois, 2008). Such findings are difficult to explain within the bottleneck view of AB.

Also, the finding that up to four targets can be identified in an RSVP stream as long as no non-targets are presented in-between is problematic for bottleneck theories; this finding is called the 'spreading the lag 1 sparing effect' (Di Lollo et al. 2005; Nieuwenstein & Potter 2006; Olivers et al., 2007; Potter, Nieuwenstein, & Strohminger, 2008). Consequently new models have been proposed that offer alternative accounts of the attentional blink phenomenon. An example is the episodic simultaneous type/serial token (eSTST) model (Bowman & Wyble 2007; Wyble, Potter, Bowman, & Nieuwenstein, 2011). According to this model, time information, necessary to keep track of the correct order of events, is sampled from temporal episodes. An episode lasts as long as the same information is processed. When new information enters the system, an episode is consolidated and a new one established. Breaks between episodes are characterized by a short period of suppressed attention needed, the AB. According to the eSTST model the AB plays an important role in parsing the continual stream of RSVP stimuli into separate attentional episodes; it reflects the suppression of attention which provides the separation.

Another example of the more recent models is the Boost and Bounce model (Olivers & Meeter, 2008). According to this model, attention boosts relevant information by responding in an excitatory manner, and blocks irrelevant input by inhibiting it. In the Boost and Bounce model, the AB is the result of a system of gating visual input via working memory. During an RSVP stream of input, the system is initially set in an inhibitory mode because it has to ward off the distracters at the beginning of the stream. On the appearance of T1, a surge of excitatory responses boosts the sensory signals and allows T1 to enter working memory. The activity peaks after T1 has already entered the working memory, explaining the (extended) lag 1 sparing. After the boost, the system sets up a strong inhibitory response to ward off T1 from further elements. This closes off working memory and results in the blink. The idea of warding off distracters was used by Colzato et al. (2008) to explain the larger AB in bilinguals than in monolinguals.

Our successful replication of Colzato et al. (2008) is further evidence that the AB effect is unlikely to be due to capacity limitations, but refers to shielding T1 (or the T1 episode) from subsequent information. It is hard to see why highly proficient bilinguals would have less processing resources than less proficient bilinguals (or monolinguals). In various studies, it has been argued that bilinguals may exhibit better working memory capacity than monolinguals (Bialystok et al., 2004; Michael & Gollan, 2005). A more likely explanation is an overzealous attentional control mechanism that suspends T2 detection during the ongoing processing of T1, as described by Taatgen, Juvina, Schipper, Borst, & Martens (2009) in their threaded cognition model (see also Niedeggen, Michael, & Hesselman, 2012). In this respect, it is interesting to notice that even the lag 1 sparing seems to be smaller in proficient bilinguals, suggesting a faster initiation of the inhibition. The latter may be limited to the Raymond et al. (1992) task, however, which consists of first identifying a white letter and then detecting a black X. In all likelihood, this transition involves a task switch, even though all stimuli are letters (Kelly & Dux 2011). It probably also requires the temporal segregation of T1 and T2 (see Akyürek & Hommel 2005; Akyürek et al., 2012, for the importance of this variable in AB). Colzato et al. (2008) observed a much larger lag 1 sparing in their task, in which participants were asked to identify and report two digits (T1 and T2) presented in a stream of letter distractors. Given that T1 and T2 formed a single episode at lag 1 in this task (same stimulus category, same task), one would not expect proficient bilinguals to do worse here (even though Colzato et al. observed a trend in this direction).

Martens and Wyble (2010) ended their review by remarking that a promising approach to shed new light on the underlying mechanisms of AB consists of studying and comparing groups of participants showing varying degrees of AB, such as patients (Husain & Rorden 2003), elderly (Lahar et al., 2001), and bilinguals (Colzato et al., 2008). We hope our study has shown the utility of investigating the last group.

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