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Attention during visual search: The benefit of bilingualism

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Abstract

Aims and Objectives/Purpose/Research Questions—Following reports showing bilingual advantages in executive control (EC) performance, the current study investigated the role of selective attention as a foundational skill that might underlie these advantages.

Design/Methodology/Approach—Bilingual and monolingual young adults performed a visual search task by determining whether a target shape was present amid distractor shapes. Task difficulty was manipulated by search type (feature or conjunction) and by the number and discriminability of the distractors. In feature searches, the target (e.g., green triangle) differed on a single dimension (e.g., color) from the distractors (e.g., yellow triangles); in conjunction searches, two types of distractors (e.g., pink circles and turquoise squares) each differed from the target (e.g., turquoise circle) on a single but different dimension (e.g., color or shape).

Data and Analysis—Reaction time and accuracy data from 109 young adults (53 monolinguals and 56 bilinguals) were analyzed using a repeated-measures analysis of variance. Group membership, search type, number and discriminability of distractors were the independent variables.

Findings/Conclusions—Participants identified the target more quickly in the feature searches, when the target was highly discriminable from the distractors and when there were fewer distractors. Importantly, although monolinguals and bilinguals performed equivalently on the feature searches, bilinguals were significantly faster than monolinguals in identifying the target in the more difficult conjunction search, providing evidence for better control of visual attention in bilinguals

Originality—Unlike previous studies on bilingual visual attention, the current study found a bilingual attention advantage in a paradigm that did not include a Stroop-like manipulation to set up false expectations.

Significance/Implications—Thus, our findings indicate that the need to resolve explicit conflict or overcome false expectations is unnecessary for observing a bilingual advantage in selective attention. Observing this advantage in a fundamental skill suggests that it may underlie higher order bilingual advantages in EC.

Keywords

Bilingualism; visual search; executive control; attention; task difficulty

A large number of studies have demonstrated that bilingualism confers cognitive benefits beyond the acquisition of a second language (see Bialystok, Craik, Green, & Gollan, 2009, for a review). Robust bilingual advantages in executive control (EC) have been observed in childhood (e.g., Adi-Japha, Berberich-Artzi, & Libnawi, 2010; Bialystok, 2010; Carlson & Melzoff, 2008; Foy & Mann, 2013; Poarch & Van Hell, 2012) and with older adults (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Luk, 2008; Gold, Kim, Johnson, Kryscio, & Smith, 2013; Ljungberg, Hansson, Andrés, Josefsson, & Nilsson, 2013; Salvatierra & Rosselli, 2011). More controversial is the existence of a bilingual advantage in a young adult population with some studies reporting an advantage (e.g., Bialystok, 2006; Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009) and others failing to do so (e.g., Bialystok, Martin, & Viswanathan, 2005; Paap & Greenberg, 2013). Difficulties with both identifying the mechanisms by which bilingualism impacts EC and experimentally isolating EC components may contribute to the mixed findings. Our approach is to focus on an underlying construct that is involved to some extent in all EC components, namely, selective attention.

The bilingual advantage in EC is usually attributed to the need to manage two concurrently active languages (Bialystok et al., 2009). As a result, bilinguals need to ignore or inhibit lexical candidates from the irrelevant language, and switch between languages when appropriate. The practice accrued by engaging these EC functions in language situations is believed to transfer to non-verbal tasks. Indeed, bilingual EC advantages for adults have been reported for inhibition (Bialystok et al., 2004, 2008; Costa, Hernández, & Sebastián-Gallés, 2008), conflict monitoring (Bialystok, 2006; Costa et al., 2009) and task switching (Prior & MacWhinney, 2010). However, underlying these components may be a more fundamental difference in selective or focused attention. Based on Miyake et al.'s (2000) finding that there is a correlation between shifting and inhibition ability, Prior and MacWhinney advanced the possibility that inhibition and shifting might rely on a shared mechanism, such as controlled attention.

Research with monolingual and bilingual babies indicates that bilingualism impacts the development of selective attention in infancy (Kovács & Mehler, 2009a) and leads to EC advantages for infants being raised in bilingual homes before language production emerges (Kovács & Mehler, 2009b). Kovács and Mehler (2009a) found that 12-month-old bilingual infants were able to simultaneously learn two different artificial speech structures, whereas monolingual infants could only learn a single structure, indicating that only bilingual infants were able to attend to two different structural regularities. Similarly, investigators found that bilingual 8-month-old infants were able to use visual cues from a speaker's face in a muted video to identify language switches for both known (Weikum et al., 2007) and unknown languages (Sebastian-Gallés, Albareda-Castellot, Weikum, & Werker, 2012). In both studies, 8-month-old monolingual infants were unable to discriminate between languages from these subtle visual cues. Sebastian-Gallés et al. proposed that the need to keep two

languages distinct in infancy may serve as precursor to the advantages observed in bilinguals across the lifespan. Importantly, this ability to distinguish between two languages from visual cues was demonstrated with unknown languages and without feedback from auditory stimuli, suggesting general enhanced perceptual attentiveness in bilingual infants. If this advantage in selective attention persists throughout the lifespan, then it should be observed in young adults when performing demanding tasks based on selective attention.

A number of studies are consistent with the proposal that bilingualism confers young adults with a superior attentional-control system. Colzato et al. (2008) observed larger attentional blink effects in bilinguals than in monolinguals, indicating that greater attention was deployed to the first target in order to ignore subsequent distractors. In a dichotic listening task, Soveri, Laine, Hämäläinen, and Hugdahl (2011) found that bilinguals identified more syllables than monolinguals when attending to input from one ear and ignoring input to the other ear. Work by Singh and Mishra (2012, 2013) has further investigated whether the degree of bilingualism impacts the efficiency of these attentional networks and whether the effects extend to oculomotor control. In a modified Stroop task, participants were required to saccade to the color patch that matched the font color of a centrally located stimulus and ignore its meaning. High proficient Hindi–English bilinguals had faster saccade latencies than low proficient bilinguals to the correct color patch in both a word version (Singh & Mishra, 2012) and an arrow version (Singh & Mishra, 2013) of the task. Taken together, these studies indicate that bilinguals are better able to maintain selective attention on goal-relevant information and ignore conflicting irrelevant information. Thus, bilingualism may enable better selective attention in order to engage in goal maintenance, conflict monitoring and interference suppression (Singh & Mishra, 2013).

Hernández, Costa, and Humphreys (2012) investigated whether bilingualism impacts selective attention during a visual search task that contains overt conflict. Participants searched for a slanted line among vertical lines. Conflict was introduced by placing the lines within different shapes (e.g., circles, squares) and biasing the expectation of a specific shape by presenting it as a cue. The slanted line could either appear in the cued shape (valid cue condition), appear in a different shape (invalid cue condition) or the cued shape did not appear in the visual search array (neutral cue condition). Hernández et al. found that bilinguals were overall quicker than monolinguals at locating the target line regardless of the condition. This increased bilingual processing speed is consistent with EC research using both flanker and Simon tasks (see Hilchey & Klein, 2011). Hernández et al. suggested that faster processing was indicative of the ability to assess task demands, monitor for conflict and engage and disengage attention. To test this explanation, however, it is necessary to rule out simple processing speed differences by including simple search conditions that do not intentionally induce conflict through setting up false expectations. The possibility, therefore, is that bilinguals are simply better at disengaging and engaging attention during visual search.

Standard search paradigms manipulate attentional demands by introducing incongruent stimuli or invalid cues that must be inhibited or ignored. In contrast, the approach used in the current study is to contrast exogenous and endogenous processes without manipulating the need for conflict resolution across trials. Exogenous processes are elicited by the stimuli,

whereas endogenous processes are internally driven. Early work by Treisman and Gelade (1980; see Treisman, 2006, for a review) found that exogenous and endogenous attention processes are differentially recruited depending on the nature of the visual search task. In feature searches where targets differ from distractors on a single dimension (e.g., a green triangle among blue triangles), participants experience a “pop out” effect in which the number of distractors does not influence response time (RT). Treisman and Gelade's Feature Integration Theory (FIT) accounts for this finding by proposing that object dimensions such as shape and color are activated automatically in parallel in a pre-attentive stage. In this type of search, targets cause bottom-up attention capture, which is an automatic, exogenously driven process and not dependent on EC. In contrast, in conjunction searches where there are at least two types of distractors (each with a feature that matches the target object), RTs increase linearly with the number of distractors. These findings indicate that individuals are engaged in a serial search and employing focused attention to find the target. FIT accounts for these results by suggesting that once the pre-attentive stage identifies the features, focused attention is used to combine each feature (e.g., blue and square). This requires endogenously driven top-down control of attention.

Research examining visual search performance across the lifespan suggests that the effects of bilingualism on attention will occur on conjunction searches rather than on feature searches. Feature searches and conjunction searches differ in their developmental trajectories (Trick & Enns, 1998). Feature search performance (parallel processing) is relatively stable across the lifespan, whereas conjunction search performance (serial processing) is more subject to a U-shaped development trajectory with age-related improvement in childhood and decline in senescence (Hommel, Li, & Li, 2004; Trick & Enns, 1998). The latter indicates the involvement of top-down control processes that mature with development and decline with age. It is on tasks that are sensitive to this developmental trajectory that are affected by bilingualism (Bialystok et al., 2004, 2008).

We used the distinction between bottom-up attentional capture in feature search and top-down control of attention in conjunction search to investigate potential differences between monolinguals and bilinguals in visual attention. Firstly, since feature searches do not require effortful focused attention, no effect of bilingualism was expected. The inclusion of this simpler condition is a means of testing processing speed. In contrast, because conjunction searches require top-down selective attention to search the display, they should be performed better by individuals with better attentional control, specifically, bilinguals. However, not all non-verbal tasks or conditions that require EC or focused attention result in observable group differences in young adults. Both Bialystok (2006) and Costa et al. (2009) only observed group differences in more cognitively demanding conditions. Thus, additional task difficulty was manipulated by modifying stimulus discriminability and distractor set size. That is, the target shape was either easy or difficult to discriminate from distractors and search displays contained either 5, 15 or 25 shapes. The largest effect of bilingualism was expected to be found on the most difficult task conditions in the conjunction search.

Method

Participants

The study included 123 participants who were English monolinguals or bilinguals. Data from six monolinguals and eight bilinguals were removed due to failure to follow task instructions (e.g., searching for the wrong target, inability to discriminate colors) or 0% accuracy in at least one condition. Data from a final sample of 53 monolingual (mean age = 21.2, $SD = 3.0$; 35 women) and 56 bilingual (mean age = 20.9, $SD = 2.5$; 40 women) young adults were analyzed. Monolinguals spoke only English on a daily basis and reported basic knowledge of a school-based second language (e.g., required French courses). Since specific language pairs (e.g., English–French, English–Chinese) have been found to not influence the nature or degree of a bilingual non-verbal advantage (Barac & Bialystok, 2012), a heterogeneous group of bilinguals was employed to increase the generalizability of the results. Bilinguals spoke English and one of 26 other languages fluently on a daily basis and reported 3.9 years ($SD = 2.6$) as the mean age of second language acquisition.

Materials and procedures

Assessment measures were the *Language and Social Background Questionnaire* (LSBQ; Luk & Bialystok, 2013), the *Shipley Vocabulary test* (Shipley, 1940; a measure of English receptive vocabulary) and the *Shipley Abstraction test* (Shipley, 1940; a measure of fluid intelligence).

Visual search task—At the beginning of each task, participants were informed which shape was the target. They were told to decide as quickly and accurately as possible whether the specified target was present among distractors found in a visual array on the computer screen. If the target was present, they pressed the “1” key and if it was not present, they pressed the “0” key on the keyboard. The visual arrays remained on the screen until participants made a response. RTs were recorded from the time the visual display appeared to the time of the key press. After the response, the next visual array appeared immediately. The target appeared randomly in 1 of 26 designated locations on the screen.

Three parameters were manipulated: search type, stimulus discriminability and distractor set size. Search type was either a feature search or a conjunction search. In the feature searches, only one feature (e.g., color) differed between the target stimulus (e.g., green triangle) and the distractor stimuli (e.g., yellow triangles). In the conjunction searches, two features (i.e., color and shape) needed to be identified in the target stimulus (e.g., turquoise circle) in order to differentiate it from the distractor stimuli (e.g., turquoise squares and pink circles). Here, effortful processing is required to search the display for the correct conjunction (the turquoise color and the circle shape). Two discriminability versions (high and low) of each search type were administered, producing four visual search tasks. In the high discriminability feature search, the target was a green triangle and the distractors were yellow triangles and in the low discriminability feature search, the target was a gray triangle and the distractors were gray squares. In the high discriminability conjunction search, the target was a turquoise circle and the distractors were turquoise squares and pink circles. Finally, in the low discriminability conjunction search, the target was a blue triangle and the

dis-tractors were blue diamonds and purple triangles. Since the colors and shapes were more visually similar, this search condition should be most difficult and be most likely to result in group differences. Within each visual search task, there were 24 positive trials and 18 negative trials. In the positive trials, distractor set size was equally divided between 0, 5, 15 or 25 distractors. In the negative trials, distractor set size was equally divided between 5, 15 or 25 distractors. The four visual search tasks (i.e., low discriminability feature search, high discriminability feature search, low discriminability conjunction search and high discriminability conjunction search) were presented in a counterbalanced order across participants.

Results

Background measures

Mean background measures for each language group are presented in Table 1. Maternal education was used as a proxy for social economic status (cf., Donaldson, Lichtenstein, & Sheppard, 2007) and was measured on a five-point Likert scale where 1 was no high school diploma and 5 was a graduate or professional degree. A one-way analysis of variance (ANOVA) showed a significant difference between the language groups only on the English vocabulary measure, where monolinguals scored significantly higher than the bilinguals, $F(1, 106) = 8.97, p < .01$ (cf., Bialystok & Luk, 2012).

Visual search results

RTs that were shorter than 200 ms or longer than 5 seconds, as well as RTs that were 2.5 SD shorter or longer than the participant's mean for each of the four search tasks were removed from the analysis. This procedure led to the exclusion of 2.5% and 2.8% of the data for the monolinguals and bilinguals, respectively. Accuracy and RT analyses were performed only where the target was present. RT analyses were performed on correct trials only.

Four-way ANOVAs for language group (bilingual and monolingual), search type (feature and conjunction), discriminability (high and low) and distractor set size (5, 15, 25) were performed on accuracy and RT data. Mean percentage accuracy for correct searches is reported in Table 2. In the accuracy analysis, bilinguals (91.3%) and monolinguals (92.0%) did not differ significantly, $F < 1$, and language group did not interact significantly with any other variable, all $ps > .12$. However, there were main effects of search type, $F(1, 107) = 162.72, p < .001, \eta_p^2 = .60$, discriminability, $F(1, 107) = 22.83, p < .001, \eta_p^2 = .18$, and distractor set size, $F(2, 214) = 58.26, p < .001, \eta_p^2 = .35$, with lower accuracy for the more difficult conditions, namely, conjunction search, low discriminability and large distractor set size. There were two-way interactions between search type and discriminability, $F(1, 107) = 45.70, p < .001, \eta_p^2 = .30$, and between search type and distractor set size, $F(2, 214) = 45.31, p < .001, \eta_p^2 = .30$, which were qualified by a three-way interaction of search type by discriminability by distractor set size, $F(2, 214) = 4.78, p < .05, \eta_p^2 = .04$. Follow-up analyses indicated that distractor set only influenced accuracy for the conjunction searches, and was largest in the low discriminability condition, confirming this as the most difficult task.

Mean RTs for correct searches are displayed in Figure 1. A four-way ANOVA indicated main effects of search type, $F(1, 107) = 639.6, p < .001, \eta_p^2 = .86$, discriminability, $F(1, 107) = 287.49, p < .001, \eta_p^2 = .73$, and distractor set size, $F(2, 214) = 124.6, p < .001, \eta_p^2 = .54$. Paralleling the accuracy data, participants were faster to respond in feature searches, high discriminability searches and smaller set size trials. These main effects were qualified by two-way interactions of search type by discriminability, $F(1, 107) = 181.0, p < .001, \eta_p^2 = .63$, search type by distractor set size, $F(2, 214) = 94.55, p < .001, \eta_p^2 = .47$, discriminability by distractor set size, $F(2, 214) = 38.29, p < .001, \eta_p^2 = .26$, and a higher order three-way interaction of search type, discriminability and distractor set size, $F(2, 214) = 29.24, p < .001, \eta_p^2 = .22$. Follow-up analyses of the three-way interaction revealed that the distractor set size effect was largest in the low discriminability conjunction search with no effect of set size on the high discriminability feature search.

There was no main effect of language group in the RT analyses, $F(1, 107) = 1.64, n.s.$, but there were significant interactions of language group by search type, $F(1, 107) = 4.12, p < .05, \eta_p^2 = .04$, and language group by discriminability, $F(1, 107) = 4.77, p < .05, \eta_p^2 = .04$. Follow-up analyses of the three-way interaction of language group, search type and discriminability, $F(1, 107) = 3.67, p < .06, \eta_p^2 = .03$, revealed that bilinguals found the target more rapidly than the monolinguals in the most difficult condition, namely, the low discriminability conjunction search, $F(1, 107) = 4.19, p < .05, \eta_p^2 = .04$.

Discussion

The purpose of the current study was to investigate whether bilingualism impacts selective visual attention in young adulthood. Performance on the visual search tasks confirmed that feature searches were easier than conjunction searches, as has been shown in previous research. Differences in the pattern of results on the feature and conjunction searches support the position that these searches recruited different cognitive processes. Consistent with research by Trick and Enns (1998) and Hommel et al. (2004), feature searches were both fast and accurate, minimally impacted by the number of distractors in the display. As expected, they were performed equivalently by monolinguals and bilinguals. These results suggest that attentional capture enabled participants to locate the target without engaging focused attention to look at each distractor in the display. They also rule out differences in simple processing speed as an explanation for bilingual advantages in visual search tasks. In conjunction searches, in contrast, discriminability and distractor set size impacted both accuracy and search times, indicating the need for more effortful processing. Importantly, bilinguals more quickly identified the target in the difficult conjunction search than monolinguals.

Our findings support the position that selective attention processes are affected by bilingualism. In visual search, when distractors each shared one of two features with the target, top-down attentional processes are recruited. Faster target identification indicates that bilinguals were better at engaging and disengaging selective attention to identify targets in the display. Our study differs from other studies on bilingual attention that have used Stroop or Stroop-like designs (e.g., Hernández et al., 2012; Singh & Mishra, 2012, 2013) that incorporated explicit conflict (e.g., invalid cues) to set up false expectations. However, these

false expectations may not best simulate the bilingual experience of choosing between alternatives. Here, we found a bilingual processing advantage in a visual search task that does not explicitly bias expectations towards an incorrect target. Indeed, as is the case when searching the lexicon or a natural setting (e.g., looking for a ripe apple in a bowl of fruit), distractors shared one or multiple features with the target. Thus, our findings indicate that bilinguals outperformed monolinguals in a task that does not require monitoring for different trial types or overcoming biased expectations (e.g., Hernández et al., 2012), indicating a fundamental advantage in engaging selective attention. Future research should employ eye-tracking techniques to investigate whether it is the time course of engaging and disengaging attention when scanning the display that is more rapid for bilinguals or whether bilinguals are better able to initiate a response once the target has been found.

It is important to note that task difficulty must be considered when evaluating whether beneficial bilingual effects are observed in young adulthood. Finding an advantage with the more difficult of the two conjunction searches is consistent with the bilingual literature on EC. Only highly demanding versions of EC measures such as the Simon task (Bialystok, 2006; Bialystok et al., 2005) and flanker tasks (e.g., Costa et al., 2009) produced group differences in young adulthood. Thus, it is important to consider how null effects inform our understanding of the nature of bilingual advantages. Kroll and Bialystok (2013) note that failure to observe a bilingual effect in young adults does not indicate that there are no cognitive consequences of dual language experience, but rather that young adults are performing these tasks in a resource-rich context, a context that has yet to be stressed by declines associated with normal aging. As a consequence, it is only when these resources are taxed that elusive underlying group differences are observed. In sum, the current study provides evidence that bilingualism impacts top-down selective attention in young adults even when explicit conflict is not presented and is observed under cognitively taxing conditions.

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Biographies

Deanna C Friesen obtained her PhD in Cognitive Psychology at the University of Western Ontario. Her research focuses on bilingual language processing and the cognitive consequences of bilingualism.

Vered Latman is currently completing her masters in Counseling Psychology at Columbia University in New York. Prior to that, she worked with Ellen Bialystok on bilingualism across the lifespan.

Alejandra Calvo completed her PhD at York University and her research focused on the effects of bilingualism on cognition. She currently leads leadership development initiatives at Alberta Health.

Ellen Bialystok is a Distinguished Research Professor of Psychology at York University in Toronto, Canada. Her research examines the effect of bilingualism and other experiences on linguistic and cognitive development across the lifespan.

Figure 1. Mean response times (and standard errors) by language group, discriminability and distractor set size for the feature search (a) and conjunction search (b).

Table 1

Mean scores and standard deviations on the background measures by language group.

Group	Mother's education level	Shipley vocabulary	Shipley abstraction
Monolinguals	3.1 (1.0)	29.0 (3.6)	13.6 (2.3)
Bilinguals	3.0 (1.2)	26.8 (4.2)	13.0 (2.8)

Note: the vocabulary test was out of 40 and the abstraction test was out of 20.

Table 2

Mean percentage accuracy and standard deviations by language group, search type, discriminability and distractor set size.

	Monolinguals		Bilinguals	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Feature search				
High discriminability				
Small	96.9	8.0	98.5	4.8
Medium	96.5	8.9	96.7	6.7
Large	96.9	7.4	96.1	7.8
Low discriminability				
Small	97.5	6.9	97.6	6.7
Medium	98.1	5.3	97.9	7.2
Large	98.7	4.4	96.7	8.7
Conjunction search				
High Discriminability				
Small	97.2	8.5	93.8	9.3
Medium	91.8	12.9	89.6	13.3
Large	85.5	19.6	82.7	14.6
Low Discriminability				
Small	89.9	15.4	92.6	13.1
Medium	82.4	19.5	78.0	19.6
Large	72.0	22.8	75.0	21.8