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Deanna Friesen
Western University, deanna.friesen@uwo.ca

Vered Latman

Alejandra Calvo

Ellen Bialystok
York University

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Attention during Visual Search: The Benefit of Bilingualism

Deanna C. Friesen[1], Vered Latman, Alejandra Calvo, & Ellen Bialystok[1]

1. York University

Address for Correspondence:

Ellen Bialystok
Department of Psychology
York University
4700 Keele Street
Toronto, Ontario M3J 1P3
Canada
Email: ellenb@yorku.ca

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Abstract

Recent research has produced mixed results about the existence of a bilingual executive control advantage in young adults. The current study manipulated both task demands and task difficulty to investigate the conditions under which a bilingual advantage may be observed during a visual attention task. Bilingual and monolingual young adults performed visual search tasks in which they determined whether a target shape was present amid distractor shapes. In the feature searches, the target (e.g., green triangle) differed on a single dimension (e.g., color) from the distractors (e.g., yellow triangles); in the conjunction searches, two different 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). All participants performed the feature searches equivalently but bilinguals were significantly faster than monolinguals in identifying the target in the more difficult conjunction search. The conjunction search required focused attention to locate the target than the feature search, providing evidence for better control of visual attention in bilinguals.

Attention during Visual Search: The Benefit of Bilingualism

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, 2013) 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). However, finding bilingual executive control advantages in young adulthood has been more elusive with some studies finding 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). This pattern of results may be explained by recognizing that children's executive control development is protracted and only operates at peak efficiency in young adulthood before declining with age (Casey, Getz, & Galvan, 2008; Craik & Bialystok, 2006). Thus, when EC is maturing or declining, there is greater variability in EC that may be modulated by the effect of bilingualism that is not possible for young adults performing simple tasks to a high level of efficiency. Observing robust differences in children and older adults indicates that underlying cognitive differences should be present in young adults, even though they are difficult to observe empirically (Kroll & Bialystok, 2013). What is required, therefore, is a clearer understanding of the conditions under which EC advantages may be observed in young adulthood and the nature of these EC advantages. Identifying the conditions that are likely to produce such performance differences in monolingual and bilingual young adults will contribute to our understanding of the nature and mechanism of the observed differences in childhood and older age. Here we expand our understanding of bilingual EC in young adulthood by manipulating task difficulty in two visual search tasks that place different demands on attention.

Arguably, one of the most important factors in observing an executive control advantage in young adults is task difficulty. Since young adults are already operating at peak efficiency, tasks that do not tax the executive control network are unlikely to reveal group differences; that is, both groups are already operating at ceiling on the task. For example, a simple version of the Simon task requires participants to make one of two responses to indicate the color of a square. The square is either placed on the same side of the computer monitor as the response button (the congruent condition) or the opposite side (the incongruent condition). The response time difference between the more effortful incongruent condition and the congruent condition is known as the Simon effect. Both Bialystok et al. (2005) and Bialystok et al. (2008) did not observe language group differences in a simple version of the Simon task with young adults, despite the presence of a bilingual advantage in their older sample (see also Gold et al., 2013). Similarly, Bialystok (2006) did not observe any effect of bilingualism on the color version of the Simon task with young adults. However, in a more difficult version that enhanced perceptual conflict by using arrows and required a high number of responses switches, young bilingual adults performed the task significantly faster than their monolingual peers. Thus, only when the Simon task necessitated high levels of executive control did evidence of the groups' underlying cognitive differences emerge.

Similarly, Costa et al. (2009) investigated the impact of task difficulty in a flanker task. In this task, participants must indicate the direction of a target arrow that is flanked by arrows that are either in the same direction (congruent trials) or opposite direction (incongruent trials) of the target arrow. The incongruent trials are more challenging since the flankers bias towards the incorrect response. Costa et al. (2009) found that in a low-monitoring condition where the majority of trials were of a single type (congruent or incongruent) no group differences were observed. However, in a high-monitoring condition where congruent and incongruent trials were more evenly distributed, bilinguals performed the task significantly faster (see also Costa, Hernández, & Sebastián-Gallés, 2008). Taken together, these findings indicate that 1) task difficulty must be considered in determining whether a bilingual advantage on executive control tasks will be observed in a young adult population and 2) cognitive benefits are not limited to incongruent trials that require inhibition or conflict resolution, but are also observed on congruent trials when conflict monitoring is required to perform the task (see Hilchey & Klein, 2011 for a review).

Since bilingual advantages have been observed in a number of EC components (e.g., inhibition, conflict monitoring and task switching), an important question is whether there is a general mechanism that underlies these components. Work with infants indicates that a bilingual advantage emerges very early in development before spoken language appears (Kovács & Mehler, 2009a) and that selective attention may be the source of these group differences. Kovács and Mehler (2009b) 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. Similarly, Sebastian-Gallés, Albareda-Castellot, Weikum, and Werker (2012) 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 and unknown languages. Monolingual infants were unable to discriminate between languages based on these subtle visual cues. Thus, these results favour the explanation that in infancy the bilingual experience leads to a heighted attentional sensitivity needed to discriminate between languages. If this advantage in selective attention persists throughout the lifespan, then it should be observed in young adults if the selective attention task is sufficiently demanding.

A number of studies have favoured the proposal that bilingualism confers individuals with a superior attentional-control system. This network enables top-down attention to engage in goal maintenance, conflict monitoring and interference suppression (Singh & Mishra, 2013). For example, Colzato et al. (2008) observed larger attentional blink effects for bilinguals than monolinguals, indicating greater attention to the first target in order to ignore the distractors. Thus, bilinguals had more difficulty identifying the second target when it was presented in close temporal succession to the first target and the intervening distractor stimuli. Similarly, for highly proficient bilinguals relevant spatial cues produced large (Colzato et al., 2008) and early (Mishra, Hilchey, Singh, & Klein, 2012) interference effects relative to no cues when identifying the presence of a target. These “inhibition of return” effects presumably occur because individuals are directing attention away from locations that are now considered irrelevant. In a dichotic listening task, Soveri, Laine, Hämäläinen, and Hugdahl, (2011) found that bilinguals identified more syllables when individuals were required to attend to a single ear and ignore input from the other ear. Work by Singh and Mishra has further investigated whether the degree of bilingualism impacts the efficiency of these attentional networks and whether the effects extend to oculomotor control. They used a modified Stroop task in which participants were required to saccade to the colour patch that matched the font colour 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 colour patch in both a word version (Singh & Mishra, 2012) and an arrow version (Singh & Mishra, 2013) of the task. Taken together, these results indicate that bilinguals are better able to maintain attention on goal-relevant information and ignore irrelevant information.

Hernández, Costa and Humphreys (2012) used a visual search paradigm to investigate whether bilingualism impacts selective attention. 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. Additionally, when participants were required to remember the cue and report it at the end of the trial, bilinguals were less impacted by the validity of the cue. That is, they were able to keep separate the representations needed for the memory task from those needed for the visual search task. This increased bilingual processing efficiency is consistent with EC research using both Flanker and Simon tasks (see Hilchey & Klein, 2011). Hernández et al. suggested that more efficient processing was indicative of the ability to assess task demands, monitor for conflict, and engage and disengage attention. That is, given that bilinguals more quickly found the target in all conditions and regardless of the cue, the advantage in monitoring was due to assessing current task demands, rather than adjusting control trial to trial (see also Costa et al., 2009). However, another interpretation is that bilinguals may simply be at an advantage in disengaging and engaging attention during visual search.

A different approach to investigating selective attention is to contrast exogenous and endogenous processes without explicitly manipulating the need for conflict resolution. Early work by Treisman and Gelade (1980; see Treisman, 2006 for a review) found that different attention processes are recruited depending on the nature of the visual search. In a feature search where targets differed from distractors on a single dimension (e.g., a green triangle among blue triangles), participants experienced a “pop out” effect in which the number of distractors do influence response time. 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 executive control. In contrast, in a conjunction search where there are at least two types of distractors (each with a feature that matches the target object) as the number of distractors increases, response times also increase linearly. 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 & square). This requires endogenously driven top-down control of attention. More recent conceptualizations of attention have defined controlled attention or selective attention as a top-down mechanism that facilitates processing relevant to the task demands. As such, individual differences in selective attention may be related to executive control (Daffner et al., 2012).

Visual search is an ideal paradigm to investigate whether task difficulty influences language group differences in visual attention. 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 in visual attention. First, since feature searches are driven by bottom-up attentional capture, they do not require effortful focused attention, so no effect of bilingualism was expected. In contrast, because conjunction searches require top-down selective attention to search the display, they are more challenging and should be performed better by individuals with better attentional control, specifically, bilinguals. However, as noted above, not all non-verbal tasks or conditions that require executive control or focused attention result in observable group differences in young adults. 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.

Method

Participants

Participants were monolingual speakers of English with only minimal knowledge of a second language (typically learned in school) or bilinguals who spoke English and an additional language fluently on a daily basis. One hundred and twenty-two participants were tested, but data from 6 monolinguals and 8 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 analysed. Bilinguals spoke English and one of 26 other languages fluently. The inclusion of multiple non-English languages enables the results to be extended to a general bilingual population. The mean age of second language acquisition reported for bilinguals was 3.9 years (*SD* = 2.6).

Materials & Procedures

Assessment measures were the *Language and Social Background Questionnaire (LSBQ),* 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. Participants sat in front of a computer monitor and determined as quickly and accurately as possible whether a specified target was present in a visual array that contained distractors. 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. Response times 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 stimuli 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 grey triangle and the distractors were grey 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 distractors 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 and was measured on a 5-point Likert scale where 1 was no high school diploma and 5 was a graduate or professional degree. A one-way ANOVA showed a significant difference between the language groups only on the vocabulary measure where monolinguals scored significantly higher than the bilinguals, $F(1, 106) = 8.97$, $p < .01$, (cf., Bialystok & Luk, 2012).

Visual Search Results

Response times (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. Error 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 error and RT data. In the error analysis, bilinguals (8.7%) and monolinguals (8.1%) did not differ on the number of errors produced, $F < 1$, and language group did not interact significantly with any other variable, all *p*s > .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 more errors 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, $F(2, 214) = 45.31$, $p < .001$, $\eta_p^2 = .30$., that 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 4-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, $F(1, 107) = 4.77$, $p < .05$, $\eta_p^2 = .04$. However these 2-way interactions were driven by a higher order three-way interaction of language group, search type, and discriminability, $F(1, 107) = 3.67$, $p = .05$, $\eta_p^2 = .03$. Bilinguals found the target more rapidly than the monolinguals in the most difficult condition, namely, the low discriminability conjunction search for all levels of set size, $F(1, 107) = 4.19$, $p < .05$, $\eta_p^2 = .04$. No significant differences were observed between groups on the other three searches.

Discussion

The purpose of the current study was to investigate the interaction of bilingualism and task difficulty on visual attention in young adulthood. Performance on the visual search tasks confirmed that feature searches were easier than conjunction searches. Differences in the pattern of results on the feature and conjunction searches support the position that these searches recruited different cognitive processes. In the feature searches, responses were both fast and accurate, were minimally impacted by the number of distractors in the display, and performed equivalently by monolinguals and bilinguals. Thus, attentional capture enabled participants to locate the target without engaging focused attention to look at each distractor in the display. In the conjunction searches, in contrast, discriminability and distractor set size impacted both accuracy and search times, indicating the need for more effortful processing. Bilinguals more quickly identified the target in the low discriminability conjunction search and demonstrated better performance in the most cognitively demanding condition.

These results make two important contributions to the bilingualism literature. Firstly, our findings support the position that selective attention is at least one of the processes affected by bilingualism. Secondly, task difficulty influences whether these beneficial effects are observed in young adulthood. With respect to the first point, studies on bilingual attention (e.g., Hernández et al., 2012; Soveri et al., 2011) have incorporated explicit conflict (e.g., invalid cues) and found that highly proficient bilinguals outperformed monolinguals. Here, we found a bilingual advantage in a visual search task that does not explicitly bias expectations towards an incorrect target. Indeed as is the case when searching a natural setting (e.g., looking for a ripe apple in a bowl of fruit), distractors shared features with the target. However, when distractors each shared one of two features with the target, top-down endogenous processes were engaged and were found to be more efficient in bilinguals. What our findings support is that it is not only the ability to meet task demands by monitoring for different trial types at which bilinguals excel, but also more basically at using selective attention to scan the display.

Despite finding a bilingual advantage in a visual search task that requires selective attention, a number of subprocesses must be engaged for successful performance and it is unclear whether one or all of these processes are modified by bilingualism. For example, there is some evidence that bilinguals have better working memory than monolinguals (e.g., Kroll, Michael, Tokowicz & Dufour, 2002; Luo, Craik, Moreno, & Bialystok, 2013) bilinguals could be better at keeping the conjunctive rule in mind during the search. Alternatively, highly proficient bilinguals have also been found to disengage their attention from irrelevant locations more efficiently than both monolinguals (Colzato et al., 2008) and less proficient bilinguals (Mishra et al., 2012); thus, when searching the display bilinguals may more efficiently disengage attention from the distractor shapes. The latter explanation seems more likely, since bilinguals only outperformed monolinguals in one of the two conjunction searches and the difference between tasks was the discriminability of the distractor shapes from the target.

Finding an advantage in only the more difficult of the two conjunction searches is consistent with the executive control literature. Only highly demanding versions of executive control measures like 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 and is observed under cognitively-taxing conditions.

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Table 1

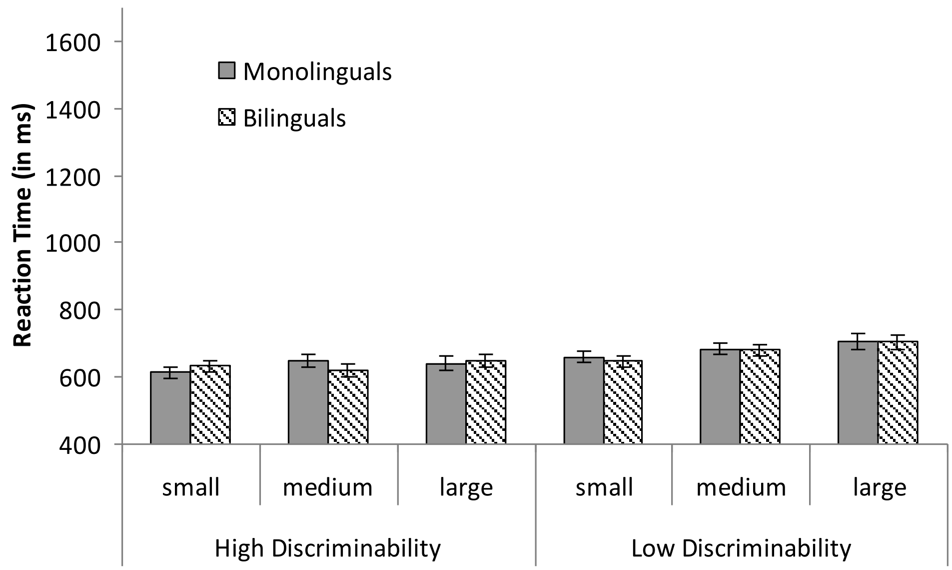
Mean Scores and Standard Deviations on the Background Measures by Language Group.

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.

Figure 1. Mean RTs (and SEs) by language group, discriminability and distractor set size for the feature search (A) and conjunction search (B).

A)



B)