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Aha! Voila! Eureka! Bilingualism and insightful problem solving☆

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ABSTRACT

What makes a person able to solve problems creatively? One interesting factor that may contribute is experience with multiple languages from an early age. Bilingual individuals who acquire two languages by the age of 6 have been shown to demonstrate superior performance on a number of thinking tasks that require flexibility. However, bilingual advantages have yet to be identified particularly on insight problems that are used as a model of creative problem solving following initial impasse. As such, the goal of the present study was to investigate the influence of language experience on problem solving performance on a matched set of insight and non-insight problems. Results demonstrate an interaction between type of problem (insight versus non-insight) and language status.

1. Introduction

Creative problem solving is an important aspect of human cognition. While our capacity for complex computation is extremely limited, creative thought can help us to succeed in spite of ourselves. The history of scientific advancement is punctuated by accounts of sudden realizations that break from past thinking and propel us forward. Yet, the circumstances and causal antecedents of creative breakthroughs, innovations, and paradigm shifts have been notoriously difficult to ascertain.

One method of studying creative problem solving is with “insight” problems. Insight problems (like the Triangle of Coins in Fig. 1) are generally defined by the tendency for individuals to approach them in initially inappropriate ways, which leads to failure and a period of inactivity during solution, or “impasse”. When solvers do reach solution, it is thought to require representational change (Ash, Cushen, & Wiley, 2009; Ash & Wiley, 2006; 2008). Further, the solution often appears in a moment of sudden illumination, or “insight.” Solution seems phenomenologically similar to real-world creative breakthroughs, often experienced as Aha! or Eureka! moments (e.g. Duncker, 1945/1972; Wertheimer, 1954/1959) and is believed to rely on the same cognitive processes. Recent research has attempted to understand exactly which processes are associated with successful solution.

First, it has been suggested that creative problem solving is facilitated by the ability to consider diverse possibilities and associations (e.g. Ansburg & Hill, 2003; Schooler & Melcher, 1995). This intuition has a long tradition in the field, as Guilford (1956) asserted that creative thinking is essentially divergent in nature. This premise provides the basis for a number of tests of creativity, including the Alternate Uses task (Christensen, Guilford, Merrifield, & Wilson, 1960), the Torrence Tests of Creative Thinking (Torrance, 1981), and the Remote Associates Task (Mednick, 1962), which assess divergent thinking ability. Insightful problem solving is also thought to benefit from the ability of a solver to identify multiple possibilities, as this may allow them to discover the solution despite reaching an initial incorrect representation.

Yet another important point is that insightful problem solving also seems to require the ability to focus on new possibilities in the face of other inappropriate paths. Often, what stymies progress on a problem is perseveration on unsuccessful solution attempts. For example, a commonly attempted incorrect solution for the Triangle of Coins problem (Fig. 1) is to move the uppermost circles (1, 2, and 3). The additional ability to direct attention towards the correct solution path, particularly in the face of other inappropriate responses, may predict creative potential (Schooler & Melcher, 1995). As disengaging from a previous set, or flexibly directing attention between alternate representations, is thought to rely on a particular set of executive functions, those functions that underlie flexible shifting of attention may be critical for insightful solutions.

Both Martindale (1995) and Schooler et al. (Schooler, 2002; Smallwood & Schooler, 2006) have suggested that success at solving insight problems may actually require a combination of both non-goal-directed associative processes and more controlled, attentionally-demanding processes. As such, one could hypothesize that insightful problem solving may be most successful in individuals who have both a large set of diverse and accessible associations, as well as superior executive functioning allowing for more flexible control of attention.

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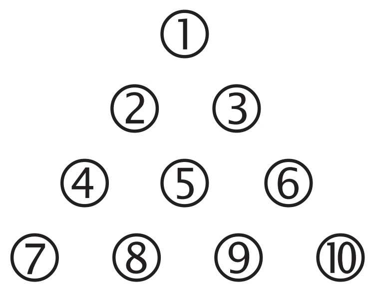
Example Insight Problem (Triangle of Coins):

The triangle below is pointing towards the top of the page. Figure out how to move 3 circles to get the triangle to point to the bottom of the page. The circles must still form a perfect triangle.



Example Non-Insight Problem:

Solve for Y.
Find the exact number that the variable Y equals by using only the necessary equations from the set of equations below.

$3Z * 3 = 27$	$2C - 9 = Z$
$P - C = 2D$	$5Z - 11 = M$
$2X = 56 + A$	$8M - C = Y$
$3Y + 14 = X$	

Fig. 1. Example insight and non-insight problems.

1.1. Bilingualism and creativity

In the present study, we explore the hypothesis that bilingualism may impart a cognitive profile conducive to solving insight problems. Prior work has suggested advantages in divergent thinking for bilingual versus monolingual individuals. In her review on bilingualism and creativity, Ricciardelli (1992) found that, in 20 of the 24 reviewed articles, bilingual individuals outperform monolingual individuals on divergent thinking tasks. More recently, Kharkhurin (2007) has found that bilingual adults demonstrate advantages over monolinguals in performance as assessed by fluency, flexibility, and elaboration on many idea generation tasks.

Explanations of this divergent thinking advantage highlight the diversity of experience encountered by bilingual individuals (Cummins, 1976; Kharkhurin, 2007). As bilingual individuals have at least two words for many objects and ideas, and because they have additional conceptual and phonological connections *across* their lexicons, their response to the presentation of a single concept may be to activate a greater and more diverse set of associations and may be less likely to lead to label-induced sets. This may explain their ability to generate a greater number of ideas than monolinguals when prompted in divergent thinking tasks.

As noted above, insightful problem solving may require not just access to a breadth of associations, but also superior attentional control. Indeed, there is reason to believe that individuals who acquire multiple languages by the age of 6 can demonstrate an advantage in the executive functions that allow for effective switching between tasks or representations. Bialystok (2001) has elaborated a popular theory in which bilingual advantages depend *not* on fluency in multiple languages per se, but rather on the acquisition of multiple languages (and thus the need to deal with lexical competition) within a critical period of early childhood (see also Green, 1998). This acquisition, occurring early in the development of executive control, influences the cognitive abilities of early bilinguals. To support this position, she and her colleagues have demonstrated advantages of young bilingual children over monolingual peers on a number of executive tasks including dimensional-change card-sort tasks (Bialystok & Martin, 2004). Bilingual children are also better able to identify and shift between multiple interpretations of ambiguous-figure and figure-ground illusions (Bialystok & Shapero, 2005), which requires flexibly directing attention to various features of the same stimulus. Further, older adults who were bilingual from an early age demonstrate similar advantages in executive function over age-matched monolinguals (Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Ryan, 2006). Second language acquisition later in life, even to the point of balanced fluency, may not yield the same cognitive advantages, as such acquisition is less influential in the development of executive functions (Bialystok, 2001).

While the evidence for this improved inhibitory control among early bilinguals has been somewhat mixed across studies (see Costa, Hernandez, Costa-Faidella, & Sebastian-Galles, 2009), there is nevertheless an indication in the literature that early bilinguals possess the ideal profile for increased success in insightful problem solving. Specific advantages in executive functioning may complement the previously discussed advantages in divergent thinking. That is, while all bilinguals may have access to diverse associations due to their multilingual experiences, early bilinguals in particular may possess superior task-switching abilities, which is also important to insight solution.

1.2. Purpose of the current study

The present study focuses on two questions. The first is whether bilinguals and monolinguals demonstrate different rates of success on a set of insight and non-insight problems. The use of insight problems here moves the understanding of bilingual creativity beyond the use of idea generation paradigms, which may not replicate real-world creative problem solving as well as insight problem solving tasks, which require a mix of free association and controlled processing.

The second question is whether these differences will be specific to individuals who were bilingual from an early age. Solving insight problems has been suggested to depend on both the ability to consider diverse associations and *also* to overcome initial biases or misconceptions. As advantages in executive function, which may underlie the ability to direct attention away from initially inappropriate problem representations, have been suggested to develop specifically in *early* bilinguals, it may be only those individuals who experience an increased likelihood of solving insight problems relative to non-insight problems. Note the prediction is not that these individuals will go about solving these problems in qualitatively different ways but rather that, due to their cognitive profiles, they will exhibit different likelihoods of success.

2. Method

2.1. Participants

One hundred and sixty-six undergraduates at a diverse, large Midwestern university participated in this research in partial fulfillment of course requirements. One hundred and two individuals were English-speaking monolinguals and 64 were bilinguals. Based on previous work on bilingualism (Bialystok et al., 2004; Bialystok et al., 2006; Costa et al., 2009), these individuals were divided into a group of 28 foreign-born bilinguals who acquired fluent English at the age of 7 or later (late bilinguals), and 36 early bilinguals who were either born in the US or were foreign born, and acquired fluency in English and another language by the age of 6. All participants, with the exception of one late bilingual, reported having attended high school in the United States. While all bilinguals in the sample spoke English, other languages varied greatly. The most commonly reported other languages were Spanish dialects (17 individuals), but responses also included Indian dialects (11), Chinese dialects (8), Korean (4), Polish (5), Tagalog (5), and Albanian (3), among others (Amharic, Arabic, Bulgarian, Greek, Lithuanian, Romanian, Vietnamese).

Table 1
Descriptive characteristics as a function of language groups.

Descriptive characteristic	Monolingual ($n=102$)	Late bilingual ($n=28$)	Early bilingual ($n=36$)
Age	18.76 (1.08)	19.21 (1.23)	18.61 (0.73)
# Female	60 (59%)	18 (64%)	23 (64%)
Ethnicity			
Asian/Pacific Islander	23 (23%)	9 (32%)	21 (58%)
Black	11 (11%)	1 (4%)	0 (0%)
Hispanic	16 (16%	8 (29%)	7 (19%)
White (Caucasian)	46 (45%)	7 (25%)	6 (17%)
Other	6 (6%)	3 (11%)	2 (6%)
Years of English fluency		7.57 (4.00)	15.67 (1.47)[a]
ACT Math score	23.62 (4.56)[b]	23.71 (4.55)[b]	25.73 (5.40)[b]

[a] 21 of 36 early bilinguals reported speaking English natively and did not provide an age of fluency. For these individuals, an age of fluency of 2 was assumed as it was the lowest value reported by a participant.
[b] ACT Math values represent only those individuals within each group who provided their ACT Math score (Ns = 90, 24, and 33 respectively).

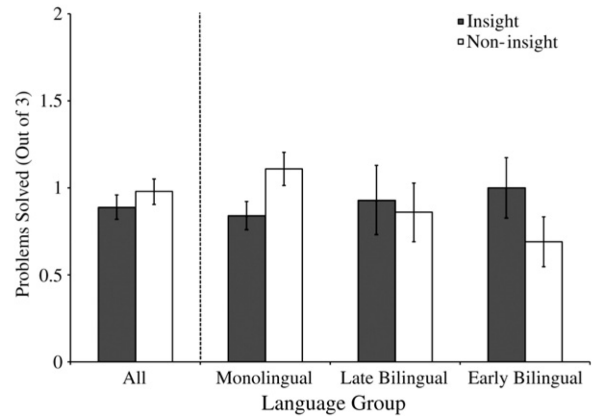


Fig. 2. Average number correct on insight and non-insight problems as a function of language group (with standard error bars).

2.2. Materials and procedure

Two types of problems were used as stimuli, three insight and three non-insight problems. Example problems are shown in Fig. 1. The insight problems were spatial object-move problems (Triangle of Coins, Matchstick Fish, and Matchstick Arithmetic). Verbal riddles that require noticing the ambiguity of a single English word (such as "move" or "married" in some classic insight problems) were deliberately avoided for this study. Previous research has identified differential effects based on verbal versus non-verbal measures of creativity (Argulewicz & Kush, 1984), perhaps due to differences in English fluency.

The non-insight problems were math problems. The items were chosen from Ash and Wiley (2008) and other pilot studies so as to be matched in difficulty within a subject-pool population including both monolinguals and bilinguals. Using a set of problems that are of similar difficulty but that do not require representational change for solution is necessary in order to ascertain whether any observed advantages are specific to creative problem solving. This is a critical design feature that allows us to identify whether these individuals demonstrate different patterns of performance on insight problems relative to their own performance on matched non-insight problems (Ash et al., 2009). Participants were given a time limit of 3 min to solve each problem. Problem presentation always alternated between problem types, but was otherwise counterbalanced for item order.

At the end of the session, all participants also filled out a demographic questionnaire in which they self-reported their age, gender, ethnicity, country of birth, native language(s), non-native language(s) spoken and, if a non-native English speaker, their age of fluency in English. Years of English fluency was computed by subtracting the reported age of English fluency from the participant's current age. For those early bilinguals who reported speaking English natively and thus did not provide an age of fluency, an age of 2 was assumed, being the lowest value provided by a participant. (For summary details, see Table 1.)

3. Results

A repeated-measures 2×3 ANOVA was performed on problem type (insight versus non-insight) and language group (monolingual, late bilingual, and early bilingual). There was no main effect for problem type ($F(1, 163) = .123$, $MSE = .083$, *ns*), meaning that, as in our previous studies, the two types of problems were matched for overall difficulty. Average solution rate (out of 3) was the same across insight ($M = .89$) and non-insight problems ($M = .98$). Further, there was no main effect for language group, $F(2, 163) = .484$, $MSE = .494$, *ns*, as monolinguals ($M = 1.95$, $SD = 1.42$), late bilinguals ($M = 1.79$, $SD = 1.34$) and early bilinguals ($M = 1.69$, $SD = 1.51$) demonstrated similar overall solution rates across all problems.

However, as shown in Fig. 2, there was a significant interaction between problem type and language status, $F(2, 163) = 3.40$, $MSE = 2.37$, $p = .036$, $\eta^2 = .04$.[1] Follow-up t-tests indicated that monolinguals demonstrated worse performance on the insight problems than on the non-insight problems, $t\ (101) = -2.395$, $MSE = .11$, $p = .02$, Cohen's $d = -.24$. Alternately, early bilinguals demonstrated marginally better performance on insight problems than on non-insight problems, $t\ (35) = 1.57$, $MSE = .19$, $p = .13$, Cohen's $d = .26$. Late bilinguals demonstrated similar performance on both insight problems and non-insight problems, $t\ (27) = .268$, $MSE = .27$, *ns*.[2] (See Table 2 for group means and standard deviations.) These results suggest that monolinguals are advantaged in solving the non-insight problems, relative to their own performance on the insight problems. However, early bilinguals show a trend in the opposite direction, suggesting an advantage in solving insight problems over non-insight problems.

Another repeated-measures 2×3 ANOVA was performed on solution times for correctly solved problems. As shown in Fig. 3, there were no differences in correct solution time for insight problems versus non-insight problems, $F(1, 64) = 1.44$, $MSE = 1263.32$, *ns*. Further, language status did not influence solution times, $F(2, 64) = 1.48$, $MSE = 3136.88$, *ns*, nor did it interact with problem type, $F(2, 64) = .04$, $MSE = 32.57$, *ns*. These results indicate that, when problems were solved, they were solved in approximately the same amount of time between language groups. This pattern suggests, as predicted, that the groups did not differ qualitatively in how they were going about solving each problem, but rather in their likelihood of success.

[1] A similar analysis collapsing across bilingual groups also showed a significant interaction, $F(1, 164) = 6.19$, $MSE = 4.30$, $p = .014$.

[2] An alternative explanation for the difference between late and early bilinguals is that the latter group has, on average, a greater number of years of fluency in English. This variable, however, did not predict performance well. Across both bilingual groups, years of fluency did not correlate with either solutions on insight problems ($r = .01$, $p = .96$) or non-insight problems ($r = .02$, $p = .89$). Within groups, there was also no relationship between years of fluency and problem solving for late bilinguals (insight, $r = -.27$, $p = .17$; non-insight, $r = .04$, $p = .84$). For early bilinguals, however, there was a significant relationship with between years of fluency and performance on insight problems($r = .43$, $p = .01$), but no relationship with non-insight problems ($r = .26$, $p = .13$). These results are consistent with the theoretical position that early and late bilingual groups are qualitatively different from one another, and that simultaneous acquisition of multiple languages during early childhood is the critical variable for this advantage, not years of fluency.

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Table 2
Mean solution rate and time as a function of problem type and language group.

	Monolingual		Late bilingual		Early bilingual	
	M	*SD*	*M*	*SD*	*M*	*SD*
Problems solved (out of 3)						
Insight	.84	.83	.93	1.05	1.00	1.04
Non-insight	1.11	.97	.86	.89	.69	.86
Correct solution time						
Insight	131.08	43.15	111.20	43.97	123.21	47.48
Non-insight	143.55	34.81	136.61	35.67	136.57	28.89

4. Discussion

This study reports a novel result that monolinguals and bilinguals demonstrate different patterns of performance on insight and non-insight problems. While our general solution rates for insight and non-insight problems were similar overall, examining inter-group differences demonstrates a previously unidentified interaction between one's ability to solve insight and non-insight problems and bilingual experience. These results suggest that, for a set of problems matched on difficulty across language groups, monolinguals may suffer under situations requiring cognitive flexibility relative to their own performance on problems not requiring such flexibility. Alternately, early bilinguals may thrive under conditions requiring such flexibility, relative to situations not requiring it. Finally, late bilinguals showed matched performance for both problem types, suggesting neither an advantage nor a disadvantage in solving insight relative to non-insight problems.

The pattern identified in these results supports the prediction that bilingual advantages in creative thinking are multi-faceted and that solution to insight problems requires more than mere divergent thinking. Both early and late bilinguals possess inter-lexical associations that may facilitate divergent thinking. This divergent advantage seems to convey some benefit to insight problem solving, as even late bilinguals do not show *worse* performance on insight than on non-insight problems as do monolinguals. However, the trend for a *benefit* to insight relative to non-insight problem solving in early bilinguals suggests an additional advantage to these individuals. The likely candidate for this advantage is differences in executive function, particularly as identified previously with task-switching and figure reversal tasks (Bialystok & Martin, 2004; Bialystok & Shapero, 2005). While the early bilingual effect is not particularly strong in this study, college populations have been difficult populations in which to identify executive function differences between monolinguals and bilinguals (Costa et al., 2009), even on low-level tasks. Few studies have attempted to investigate whether those differences translate to differences on high-level problem solving tasks such as those used in this study. Nevertheless, a critical next step in this line of research will be to bridge the two methodologies by measuring both task-switching ability and problem solving performance. Such a paradigm could address whether differences in executive functioning mediate the relationship between bilingual status and insight performance.

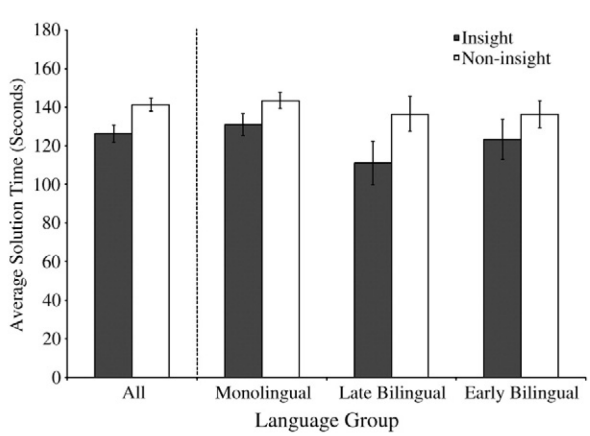

Fig. 3. Average correct solution time on insight and non-insight problems as a function of language group (with standard error bars).

Another interesting set of issues that cannot be fully addressed by these results is the degree to which culture influences this pattern of effects. There are several possible questions related to culture. One is whether benefits of bilingualism on creative problem solving may be due in part due to broader cultural experiences and not just access to multiple lexicons per se. A second related question is whether the effects of bilingualism may be better described as cross-cultural differences. In terms of the first question, multilingual experience is often associated with exposure to multiple cultures. Research has also identified a role of multicultural experience in influencing creative cognition, both in terms of culture of origin influencing creative potential (e.g. Kaufman & Sternberg, 2006; Kharkhurin & Samadpour Motalleebi, 2008; Niu & Sternberg, 2001) and in cultural experience (Maddux & Galinsky, 2009) and cultural priming (Jia, Hirt, & Karpen, 2009) improving creative problem solving. As such, one might argue that the multilingual effects identified in this study may be in part due to differences in multicultural experience between the groups. Unfortunately, we do not have measures of multicultural experiences for our current sample that would allow us to disentangle the linguistic and cultural influences, but this is another important direction for future research.

In terms of examining cross-cultural differences, we note that the sample obtained in this study did not have a large enough number of observations within each cultural group to allow for meaningful subgroup analyses. However, we also note that our bilingual samples were far from representing a single cultural, ethnic, or linguistic group. When we informally examined the patterns for Asian, Hispanic and Caucasian early bilingual groups, the same trend favoring insight performance over math performance was present in all three groups. This suggests that the effects of early bilingualism are not being driven by one particular cultural group. Finally, even if culture is important to creativity, the advantage of our early bilinguals over the late bilinguals suggests there is an important role for early bilinguals' executive function advantages, which have been found to be relatively consistent across various cultures and language pairs in other studies (Adesope, Lavin, Thompson, & Ungerleider, 2010).

The main contribution of this study is in providing the first evidence that early bilingualism can confer relative advantages on insight problem solving versus non-insight problem solving tasks, especially as compared to monolinguals who show the opposite pattern. It also provides support for theories suggesting that insightful problem solving requires a combination of access to a breadth of potential associations as well as superior executive functioning. A final contribution of this study is in showing that the potential executive function advantages from early multilingual experience can extend beyond performance on low-level attentional tasks and can be seen in promoting the kind of innovative problem solving and revolutionary thinking that may underlie real-world breakthrough discoveries.

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