HOW DOES AGE OF ACQUISITION AND FLUENCY AFFECT THE BILINGUAL ADVANTAGE?

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ABSTRACT

It has been well established in the literature that there is a cost to switching tasks. Although it has been shown that this switch cost is robust, there has been a lot of research into areas where people with different capabilities have cognitive advantages that allow them to lower task switch costs. One such area is bilingualism. Prior research has shown that bilinguals reliably show lower switch costs than monolinguals; however, it is unclear how the bilingual advantage emerges. Researchers have shown that fluency is likely more critical than age of acquisition (AoA), but the two factors are often confounded in prior studies. This study investigated the nature of the bilingual advantage toward task switching to understand the roles that AoA and fluency play in the bilingual advantage. Early AoA participants ($N = 37$) and late AoA participants ($N = 21$), categorized into low vs. high fluency groups, performed a cued color/shape task switching experiment that manipulated crosstalk (interference from the other task) and cue-target interval (CTI; preparation time) across blocks. Results showed a local switch cost for reaction time and error rate, along with a practice effect and an interference effect, replicating prior studies on task switching. A significant effect of CTI showed the inverse of what was expected for the preparation effect, which may be due to the long CTI being too long, leading to attention wander. There was no main effect of AoA or fluency, though both factors entered into higher-level interactions. The early AoA and low fluency group consistently showed better performance than the other groups. This may be due to that group having the most video game players with the greatest experience, which seems to be a confounding participant variable. Future research should consider determining at what length CTI may become too long, as well as how video game experience interacts with the bilingual advantage. The design implications from this study are that interference from task switching should be reduced from interfaces where

possible. Moreover, designers of systems that utilize alerts or reminders should be aware that presenting these cues too early may reduce their effectiveness.

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AoA	Age of Acquisition
CTI	Cue-Target Interval
ER	Error Rate
EVGP	Early Video Game Players
LVGP	Late Video Game Players
nVGPs	Non-Video Game Players
RT	Reaction Time

CHAPTER 1

INTRODUCTION

It is well understood that there is a part of the brain that must keep control of cognitive processes to coordinate what should be done at any moment. An example of this can be seen within an office setting. In the middle of writing an important email, a worker is interrupted by a new email about something unrelated. Opening the new email to read it, it takes a few seconds to orient to the details of the new email. Going back to finish the original email, it takes time to readjust the worker's mindset, and the office worker is likely to make more errors than if s/he did not see the incoming email. This is an example of a task switch. Humans regularly have to switch between tasks throughout the day, but this process of task switching comes with a cost. Rogers and Monsell (1995) found that there is a consistent delay in responding when switching between tasks and that accuracy of performing the new task is also hindered.

The task switching cost is robust but can be reduced in certain cases (Monsell, 2003; Rogers & Monsell, 1995). One such case is with bilingual participants, who have a cognitive advantage likely due to their consistent need to switch internal states between languages. The lower switch cost is referred to as the bilingual advantage (Barac & Bialystok, 2012; Bialystok, 2010, 2011; Bialystok & Barac, 2012; Costa et al., 2008; Wiseheart et al., 2016). The goal of this thesis is to further explore how the bilingual advantage in task switching emerges, whether the advantage is more consistent with an explanation based on age of acquisition (AoA), fluency, or a combination of both. In the following sections, the classic task switching paradigm is reviewed along with its associated costs. Then, a section follows describing how the task switching costs can differ across groups of individuals of varying characteristics. Common characteristics that have been researched to show differing switch costs are age (Cragg & Nation, 2009; Davidson et al., 2006; Reimers & Maylor, 2005; Wasylyshyn et al., 2011), interactive media usage (Alzahabi & Becker, 2013; Boot et al., 2008; Hartanto et al., 2016; Strobach et al., 2012) and bilingualism (Bialystok et al., 2008; Pelham & Abrams, 2014; Prior & MacWhinney, 2010). The paper then goes into further detail about the bilingual advantage, discussing the current research on how the bilingual advantage emerges, and the different components that may affect the advantage. The paper ends with a study that compared the task switching costs associated with bilinguals who acquired their second language at an early or late age, and who were lower or higher in fluency.

1.1. Task Switching and Its Associated Costs

The origins of the task switching cost originate from a paper nearly a century old. Jersild (1927) had participants perform two different tasks. The first task involved subtracting three from a provided number (e.g., 27, where the correct answer is 24), and the second task asked the participant to provide a common opposite word to a given word (e.g., hot, where the correct answer is cold). These tasks were tested in single-task, or "pure" blocks, that involved performing the same task repeatedly, as well as a mixed block that involved performing one task and then switching to the other task. Jersild found that reaction times were shorter in the mixed block than the single-task block. Jersild's paper was revisited in 1976, which replicated the experiment, and expanded on the original findings with other experiments (Spector & Biederman, 1976). In one experiment, Spector and Biederman's (1976) had participants add 3 to a given number for one task or subtract 3 from a given number for a second task. With both stimuli being numbers, the stimulus itself does not identify precisely what the task is without an addition cue; therefore, creating ambiguity of the response. In this situation, Spector and Biederman (1976) found that creating ambiguity of the task at hand caused the opposite of

Jersild's findings, and the reaction time of the mixed list became dramatically worse than pure lists.

Cellier and Eyrolle (1992) studied task switching using a more complex task. In their experiment, numbers and letters scrolled across a screen, and participants had to identify whether a particular part of the sequence followed a given rule, which they referred to as a single task. For example, a rule for one task could be "an even number followed by a vowel." The researchers tested the participants by having them do all six tasks separately, by having them perform two tasks simultaneously (a dual-task scenario), and a task switching scenario, where the participants had to switch back and forth between tasks. The researchers found a significant difference between the reaction time and error rate at the beginning of the task compared to the end and that there was a deficit to reaction time when switching between tasks (Cellier & Eyrolle, 1992). A few years later, further research was performed, identifying a reliable cost when switching between tasks (Rogers & Monsell, 1995).

Rogers and Monsell's (1995) first experiment presented a number and a letter together in 1 of 4 boxes. Participants were instructed that when the number and letter appeared in two specific boxes, the task was to look at the number, and if the number was odd, press a button with the index finger on one hand; if the number was even, press a separate button with the index finger on the other hand. When the letter and number combination appeared within one of the other two boxes, the subject needed to press different buttons depending on whether the letter was a consonant or a vowel. The combination of characters would continue to appear in subsequent boxes going around in clockwise turns such that the participant knew that a switch of tasks was going to occur reliably. The researchers found that the reaction time was slower, and error rates were higher when the participant switched between tasks compared with when they did not switch between tasks (Rogers & Monsell, 1995).

Rogers and Monsell (1995) also tested the participants on multiple days and found that there was a practice effect, which reduced the error rate and reaction time, but the practice effect was not enough to eliminate the switch costs entirely. The subsequent experiments attempted to remove switch costs by preparing the participant for the new task more efficiently or removing parts of the task that may lead to the switch cost. The second experiment involved increasing the time between task switches to allow participants time to prepare for the task switch. However, because different intervals were used throughout, participants were unable to anticipate the switch properly, and they did not find a reduction in switch costs. Rogers and Monsell's Experiment 3 was the same as Experiment 2, with the exception of a consistent interval used between the response and the next stimulus within a block. The interval was manipulated between blocks so that the researchers could compare the differences between preparation time. The participants completed two practice switching blocks with a 150 ms response-stimulus interval and were then tested at five different intervals: 150 ms, 300 ms, 450 ms, 600 ms, 1200 ms. Each interval was performed for four blocks. The cost of switching tasks was reduced, but again it was not eliminated. Since the switch costs persisted and leveled out with a larger interval between tasks, this means that there is an underlying cost that cannot be removed by allowing participants time to prepare themselves to switch between tasks (Rogers & Monsell, 1995).

In Rogers and Monsell's (1995) first three experiments, there was a lot of crosstalk occurring, which is the interference from the other stimulus which could confuse participants by making them believe that they should continue with the existing task, even though the task has switched. There are two types of crosstalk. Congruent crosstalk is where the stimulus would lead to the correct response, whether doing the current task or the previous one. Incongruent crosstalk is where the prior task's stimulus would lead to an incorrect response for the stimulus on the current task. After the first three experiments, it is not clear whether the switch cost is only due to crosstalk or other executive control issues. Thus, in Experiment 4, the test was modified to remove all crosstalk issues by replacing the potentially interfering character from the previous task with a neutral character unrelated to both tasks (i.e., %). The results of Experiment 4 replicated Experiment 3 with lower switch costs since it removed some interference, reducing inhibition, but was similarly unable to remove the switch costs entirely. In Experiment 5, a cue was presented prior to the new task to help participants prepare for the task switch. Again, the switch costs were reduced but not eliminated. In the final experiment, Rogers and Monsell (1995) used the same number and letter tasks as before, except now instead of switching tasks after two trials, the switch now occurred after four trials of each task. This last experiment showed not only a cost to the initial trial after a switch, but additional lower costs to the subsequent trials after that, referred to as a mixing cost. These findings effectively mean that there are additional costs from mixing between two tasks other than the initial switch cost (Rogers & Monsell, 1995).

There have been further attempts to eliminate the task switching cost. Koch et al. (2004) had subjects switch between 3 different tasks. One task involved deciding if a number was odd or even, another task involved deciding if a number was greater than or less than 5, and a third task involved simply pushing both response buttons at the same time. The purpose of the third task was to inhibit the response and determine if the ordering of task switches had any effect. Koch et al. (2004) found that switch costs generally remained. However, the greater switch costs occurred when the participant was made to switch to the task that they had performed prior to the last one (*n*-2). In other words, if a participant performed task A, switched to task B, and then switched to task C, a similar switch cost would occur for the switch AB as well as BC. However, if the participant performed task A, performed task B, and then had to switch back to task A, there was a larger switch cost in the last switch to A than the switch to task B. Or more simply, ABA had larger switch costs than ABC.

Based in part on the findings described above, the task switching paradigm identifies several different types of costs. The switch cost is the cost of longer reaction time and lower accuracy when switching between tasks (Monsell, 2003). The preparation effect is that the switch cost is reduced through preparation and cueing, but it does not entirely disappear. That is, there is a residual switch cost, meaning that even with substantial preparation, the level of cost reduction plateaus to the point of a base cost. There is also a mixing cost, which means that subjects generally perform worse on blocks where tasks are mixed, even on repeated tasks compared to pure blocks of a single task (Monsell, 2003). Based on these general and specific switching effects, researchers make a distinction between local (also called specific) versus global (also called general) switch costs (Belleville et al., 2008; Huff et al., 2015; Kray & Lindenberger, 2000; Reimers & Maylor, 2005). A local switch cost is defined as the difference of reaction time and error rate between switch and non-switch trials within a switch block, and a global cost is the cost of non-switch trials within a switch block, compared to a single-task block.

The task switching cost is primarily considered to be associated with problems of inhibition or interference. Costa and Friedrich (2012) investigated where process inhibition may occur when switching tasks in two experiments. Experiment 1 attempted to determine whether conflict via multivalency of stimulus or response was required to create inhibition. To make the stimulus univalent, the researchers had the participants switch between tasks with no characteristics in common. To make the response univalent, the participants had to click buttons on a special response box with separate buttons for each task, all equally distant from the hand position. The participants performed both a single-task block and a mixed-task block. From the first experiment, the researchers identified that inhibition still occurred with univalent stimulus and response, meaning that there is a general problem of getting one task out of the brain and loading up the next one. Experiment 1 also showed that back inhibition switches (going back to the task prior to the one just finished, such as “ABA”) had a higher cost than switching between three separate tasks one after the other, replicating Koch et al. (2004). Experiment 2 was similar to the first, except now the tasks all contained one relevant feature from another one. Costa and Friedrich (2012) identified that proactive interference (where the task on trial N-1 was the distractor on trial N) was at the task level, meaning that any part of the task could cause interference in the new one. The researchers also identified negative priming (where the task ignored on trial N-1 was the relevant task on trial N) was at the level of the stimulus instead of the task set (Costa & Friedrich, 2012).

Since task switching is heavily linked to executive function, similar tests are often used to measure cognitive control. The Simon task is another example of a task requiring cognitive control and inhibition of interference. In the Simon task, a stimulus will occur on the same side as the participant’s response or the opposite side. A non-spatial attribute of stimuli will indicate which response is to be made. Simon and Rudell (1967) found that when the stimulus occurs on the same side as the response, the response time is significantly shorter than when the stimulus is incongruent with the response location. The Eriksen Flanker task is yet another similar task used to test inhibition related to cognitive control. The Eriksen Flanker task (often referred to as simply “flanker”) involves a target stimulus appearing in a fixed position that determines whether a participant should select one response or a different one. The fixed position target stimulus that appears is flanked by additional noise letters. The researchers found that response times were shorter when the target was surrounded by the same letter, or letters signaling the same response, and longer when surrounded by letters signaling the opposite response (Eriksen & Eriksen, 1974).

1.2. Task Switching Across Various Groups

The studies reviewed above were mainly laboratory studies with college-aged students. However, there has been interest in demographic factors that may contribute to the magnitude of task switching costs and related executive control. Age and other demographics of people, such as those who utilize interactive media more or less, and bilingual or monolingual people have been vastly researched due to characteristics of cognitive control associated with these demographics.

1.2.1. Age

Cognitive function changes over time, with the human brain developing functionally throughout childhood and deteriorating in older age. Curiosity to understand the human mind has naturally led to a vast amount of research about how executive function changes across age groups. Cragg and Nation (2009) compared the performance of children aged 5- to 8-years old with those aged 9- to 11-years old using a task switching experiment. To make it easier and more attentive to children, the child had to identify which team a soccer player belonged to. In the first task, the child had to identify which team the player belonged to based on the color of their jersey. In the other task, the child had to identify the team that the player belonged to based on the pattern on their jersey. The children were tested on single-task blocks followed by a mixed-task block. The researchers found that the older group of children had smaller switch costs, smaller mixing costs, and smaller switch costs on incongruent trials, though both age groups had significantly larger switch costs in incongruent compared to congruent trials (Cragg & Nation, 2009).

Similarly, Davidson et al. (2006) compared the performance of young adults (mean age 26.30 years) with children aged 4-13 by having them take a series of tests of inhibition and working memory. One of the tests was referred to as the dots test. The dots test involved showing either a gray circle or a circle containing vertical stripes at either side of the screen. If a gray circle appeared, the participant had to press the button on the same side as the circle appeared, or if the circle was striped, press the button on the opposite side as the circle appeared. This combination allowed researchers to obtain reaction time to congruent and incongruent trials, and in pure and mixed conditions. The researchers found that the reaction time of the adults was shorter across all tests. In the more difficult mixed condition trials, adults slowed down, perhaps to account for providing greater accuracy. On the other hand, children were more likely to maintain a similar pace, resulting in lower accuracy on the mixed condition trials, though the overall reaction time cost remained similar between groups (Davidson et al., 2006).

Older adults have been compared to many different age groups. Reimers and Maylor (2005) performed an internet-based task switching experiment with 5,271 participants between the ages of 10 and 66. Four photos were used, a woman with a happy face, a woman with an unhappy face, a man with a happy face, and a man with an unhappy face. The two tasks were to either identify whether the photo was of a male or female, or to identify if they were happy or unhappy. Reimers and Maylor (2005) analyzed whether the age effects on switch costs followed a U-shaped function and identified that age was a significant predictor of error rates in single-task and mixed-task blocks, and age-squared was a significant predictor of reaction time in single-task and mixed-task blocks. Across both single-task and mixed-task blocks, the researchers identified both switch costs and mixing costs, as well as a significant quadratic component that linked age with both reaction time and error rate. These findings meant that switch costs were higher for children, decreased during adulthood, but then the switch costs got worse again during older age (Reimers & Maylor, 2005). A meta-analysis identified that older adults have cognitive decline, increasing reaction time in single-task blocks as well as switch tasks, increasing both global and local switch costs (Wasylyshyn et al., 2011).

1.2.2. Interactive Media

As the costs associated with task switching are considered likely an issue of not being able to inhibit the prior task, there has been research into groups that may have some advantage of switching mental functions quickly, such as video game players. Video game players have been researched because many video games involve switching between small tasks very quickly, such as locating supplies, navigating, and identifying and fighting enemies (Boot et al., 2008). The following research provides some further insight into cognitive abilities such as task switching with regard to video games and other interactive media.

Strobach et al. (2012) performed two experiments to understand if video games have any effects on switch costs and different scenarios in which a link may occur. Experiment 1 compared gamers and non-gamers, where gamers were participants that played 6 or more hours of video games per week, and non-gamers were those that played less than 1 hour per week. The researchers used Rogers and Monsell’s (1995) Experiment 1 set up and found that gamers had a lower error rate and a shorter reaction time when switching between tasks. Experiment 2 attempted to identify any causal relationships around video games. In this experiment, researchers took a set of non-gamers and split them up into three groups. All groups performed the task switching experiment. Over 4 weeks, one group practiced playing an action game for 15 hours; one group practiced playing a puzzle game for 15 hours; the third group did not practice any video games. After the 4 weeks, all participants returned to retake the task switching experiment. Strobach et al. (2012) found that only the practice of playing action video games had any effect, reducing switch costs with regard to both reaction time and error rate. In contrast, those that practiced puzzle games and those that did not play games at all both did not significantly differ in performance from their earlier test.

Subsequently, Hartanto et al. (2016) tested participants that were split up into three groups based on their video game experience. One group consisted of early video game players (EVGPs), which meant that they played video games actively prior to the age of 12. The second group consisted of late video game players (LVGP), comprised of participants that had actively played video games from the age of 12 or older. It is worth noting that the only significant difference between the first two groups was the onset of playing video games. The first two groups currently played video games around the same amount, and their self-rated proficiency was similar. The third group consisted of participants that did not play video games (nVGPs). All participants were tested with a task switching experiment, where the participant had to choose between either a color (red or green) or a shape (circle or triangle) from a bivalent stimulus, given a cue to indicate the task. Participants were tested with both single-task and mixed-task blocks. The results of the task switching experiment showed that EVGPs had lower switch costs than both LVGPs and nVGPs, who did not significantly differ. Mixing costs showed different results, however, with the EVGPs and LVGPs not differing, but both groups showed significantly smaller mixing costs than nVGPs. This suggested that the age the participants started playing video games was a better indicator of switch costs than the frequency of video games played on its own, but that mixing costs improved based on extensive periods of video game experience (Hartanto et al., 2016).

Similar to video gaming, media multitasking requires switching between different tasks frequently, and as such has been researched to determine its effect on task switching and cognitive control. Alzahabi and Becker (2013) performed two experiments with two groups of participants categorized as either light or heavy media multitaskers. For Experiment 1, the participants were tested on task switching tests and a dual-task test. The task switching experiment was a variation of the ones used by Rogers and Monsell (1995), being the letter task and numbers task. The primary difference was that the responses were split to be univalent, and there was an indication on screen to the current task rather than the task being based on the position of the stimuli. More specifically, participants in Rogers and Monsell's (1995) study used the same buttons to indicate whether a letter was a vowel for one task, then used the same button to indicate whether a number was an odd number and used a separate button for the other answer on each task. In contrast, Alzahabi and Becker's (2013) participants used one hand to press 1 of 2 buttons, indicating whether a letter was a vowel or a consonant, and their other hand to press 1 of 2 buttons for the number task. This distinction between responses allowed for easier comparison with the dual-task test, which required both hands such that two answers (performing the letter task with one hand and the numbers task with the other) could be given simultaneously. The dual-task experiment was similar to the task switching test, except there were cases that the participant had to specify a response for both stimuli shown on the screen. For the task switching experiment, the researchers found that heavy media multitaskers had smaller switch costs, though they found no difference in mixing costs between the light and heavy media multitaskers.

For the dual-task experiment, there were no significant differences identified between the two groups (Alzahabi & Becker, 2013).

Prior to this research, Ophir et al. (2009) had similarly researched light and heavy media multitaskers using Rogers and Monsell's (1995) letter-number task switching experiment and bivalent responses, identical to the original experiment. Ophir et al. (2009) found that heavy media multitaskers had a *higher* switch cost than light media multitaskers, opposite to the result found by Alzahabi and Becker (2013). As such, Alzahabi and Becker (2013) clarified their results by attempting to directly replicate the conditions of Ophir et al. (2009) to determine whether any experimental design conditions impacted the results. However, even repeating the experiment performed by Ophir et al. (2009), Alzahabi and Becker (2013) again found that heavy media multitaskers had smaller switch costs. Due to the age of social media in society, further research will likely be able to examine whether there are differences between individuals that became heavy media users at an early age compared to those introduced to media during adulthood.

1.2.3. Bilingualism & Executive Function

The group that has been most frequently researched for potential executive function advantages is people that speak multiple languages. The reason behind these studies is that people speaking multiple languages have to switch between different languages continuously, and this constant switching may create a life-long series of practice sessions inhibiting interference of a different language, leading to higher levels of cognitive control. Several studies have shown that there is a "bilingual advantage" to task switching and other tasks that require a lot of cognitive control (Barac & Bialystok, 2012; Bialystok, 2010, 2011; Bialystok & Barac, 2012; Costa et al., 2008; Wiseheart et al., 2016). Pelham and Abrams (2014) had participants perform a picture-naming test and a flanker task to measure executive function. The researchers found that monolinguals were able to name pictures significantly quicker than bilinguals. In contrast, in the flanker task, bilingual participants were able to react quicker in incongruent trials than monolingual participants, resulting in smaller switch costs.

Prior and MacWhinney (2010) showed a distinct bilingual advantage in task switching in a study with 45 monolingual and 47 bilingual students, who had all learned a second language prior to 6 years of age. Prior and MacWhinney had the participants perform a task switching experiment involving two tasks: a shape task and a color task. As shapes are recognized through pattern recognition alone, and colors are recognized through physical traits within the eye, neither requires any lexical analysis, including which known language may be relevant. Therefore, the use of a shape task and a color task eliminates any concerns of language tasks, such as the vowel/consonant task used by Rogers and Monsell (1995). The task switching experiment consisted of three sections. The first section involved single-task blocks, the second section tested the participants on mixed-task blocks, and the third section again tested subjects on single-task blocks, in the opposite order from the first section. Prior and MacWhinney (2010) found that bilinguals incurred a significantly lower switch cost than monolinguals when going from one task to another within a mixed-task block. Mixing costs, which is the difference between the performance in a single-task block and the non-switch trials within a mixed-task block, did not differ between bilinguals and monolinguals. These findings suggest that the bilingual advantage is more closely related to an increased ability to reconfigure tasks by ignoring the old task and putting the new task in focus, rather than a general continuous mechanism of cognitive control (Prior & MacWhinney, 2010).

A significant amount of research around bilingualism and task switching is in older adults, in an attempt to understand if the cognitive advantages change across development or if they are the key to a way of guarding oneself against cognitive decline associated with old age. Bialystok et al. (2008) compared the performance of bilingual and monolingual subjects who were either young (mean age = 20.7 years) or older adults (mean age = 67.2 years) across several tests of working memory, lexical access tasks, and executive control tasks. Bialystok et al. found that both the younger monolingual and bilingual groups performed better in the working memory tasks than the older monolingual and bilingual groups, and that younger bilinguals did better than younger monolinguals. On the lexical access tasks, researchers identified that monolinguals scored higher than bilinguals in their respective age groups, meaning that monolinguals were able to more quickly come up with words associated with an object or description. The executive control tasks consisted of a Simon task, a Stroop color-naming task, and a Sustained Attention to Response Task (SART). The researchers did not find any significant differences in the SART test, but the Simon task and Stroop task both showed that younger adults outperformed older adults. In the Simon task, the younger bilinguals outperformed the younger monolinguals, and in the Stroop task, bilinguals in both age groups outperformed monolinguals in their respective age group. These findings further reinforce the idea that a bilingual advantage gives people higher levels of cognitive control, which lasts throughout the lifetime (Bialystok et al., 2008).

1.3. Bilingual Advantage Emergence

Given the research above, there are clear signs of a bilingual advantage of cognitive control. Unfortunately, how the bilingual advantage emerges is harder to identify. The ideal studies would take a set of participants from a starting position of monolingualism, guide them through learning a second language into fully proficient bilingualism and having the participants take a series of executive functioning tests at multiple points throughout this endeavor. However, such a study would be impractical, given the time taken to learn a language and the difficulty with integrating the person in a different world of people to practice the second language. Such a study would also be problematic due to the obviously compounding practice effect and the fact that both very young and old participants would need to be excluded. The reason for this is that young participants do not provide a sufficient baseline of monolingualism, and older participants are more likely to take longer to learn a new language and could pass away before the end of the study. Therefore, researchers have to determine the emergence of the bilingual advantage by asking more specific, directed questions. The following sections discuss research that has investigated how the bilingual advantage may emerge, either through the basis of the age a second language was initially acquired, how proficient the user is in both languages, or how frequently the person uses and switches between both languages.

1.3.1. Age of Acquisition

Many researchers have investigated the effects of second language acquisition throughout childhood and adolescents as the most common time to learn multiple languages. Bialystok et al. (2014) studied monolingual children, half of which were between 7.0 and 8.4 years (grade 2), and half were between 9.9 and 11.5 years (grade 5). Half of these children in each group were in English education, whereas the other half were in immersion education. The researchers tested the children in grammatical judgment. The grammatical judgment task was designed by using 40 sentences and creating a grammatically incorrect version that still had meaning, and an anomalous sentence that was a grammatically correct sentence but did not make sense due to an impossible pairing of actions with agents. This meant that the 40 correct sentences, and two sets of incorrect sentences combined together to make 120 sentences. The children then had to listen to these sentences and respond whether the sentence was a correct sentence or not. Similar grammatical judgment tasks have previously linked to more executive control (Moreno et al., 2010). For the anomalous sentences, Bialystok et al. (2014) identified an interaction of grade and language group, with both sets of children in the younger age group scoring similarly but the children in immersion education scoring significantly better in the older age group. These results suggest that the bilingual advantage appeared gradually throughout language learning between grades two and five (Bialystok et al., 2014).

When considering learning at a later age, researchers have found that people learning a second language after the age of 13 can still produce a bilingual advantage (Pelham & Abrams, 2014). Vega-Mendoza et al. (2015) compared first- and fourth-year university students majoring in either a second language or literature/humanities. The researchers used the Visual Elevator subtest of the Test of Everyday Attention (TEA) in order to test participants' task switching abilities (Robertson et al., 1994). The Visual Elevator subtest involves seeing the numbers on an elevator panel lighting up, indicating which floor the elevator is on. As the elevator changes floors up and down, the participants have to count up or down to indicate which floor the elevator is on. The score given to a participant is based on the error rate and reaction time taken when the elevator switches direction (Chan et al., 2006). Vega-Mendoza et al. (2015) found that both the second language and literature/humanities groups performed similar to each other in the first year, but the group learning a second language performed significantly better than the literature/humanities group in the fourth year. Thus, even as late as college-age, a similar advantage in learning a second language has been identified, though in this paper, it is not clear how much knowledge of a second language the students had prior to college or the amount of frequent use that was involved (Vega-Mendoza et al., 2015).

To discover if short-term language-switching training can aid in improving executive function in non-linguistic domains, Timmer et al. (2019) took 68 Catalan-Spanish bilingual participants and split them into two groups. One group was trained in linguistic task switching by being shown pictures of drawings of objects. The participant's aim was to say what the object was, and a cue would let them know which language should be used. The other group was trained in non-linguistic task switching using different colors and shapes, where the response was a key based on either the shape or the color, depending on the task at the current time. Each group was trained through the same set of single-task and mixed-task blocks, the same number of times. The researchers tested both groups with a task switching experiment before and after the training was performed and found that both groups showed reduced switch costs after the training. Still, the group that practiced linguistic task switching had a significantly greater improvement than the group that practiced non-linguistic task switching. The researchers also found that the mixing costs were reduced similarly for both groups (Timmer et al., 2019). Again, these findings indicate that the bilingual advantage can potentially be learned.

1.3.2. Frequency of Use

Other than consideration of children learning a second language, the above research did not take into account that using multiple languages is a skill, and along with proficiency of a language, it is on a spectrum. One may consider that they only know one language, one may consider that they know multiple languages fluently, but there is a large gray area between these two extremes. Multiple researchers have considered the different categorization of monolingual versus bilingual, or the proficiency of second language use rather than the AoA may be behind some mixed results representing the bilingual advantage (Blanco-Elorrieta & Pylkkänen, 2018; Yow & Li, 2015). The following research has considered whether the frequency that a second language is used or the proficiency of that second language may be more closely associated with the bilingual advantage than the AoA.

Yow and Li's (2015) study included participants that had all learned a second language before the age of 7 and had them perform the number-letter task switching experiment from Rogers and Monsell (1995). A regression model for the regular use of both languages and AoA of the second language predicted a significant 15% of the variance of mixing costs. However, the mixing cost was only significantly predicted by regular use, not the age that the second language was acquired. This means that the bilingual advantage may not necessarily come from the age of language acquisition but merely whether both languages are frequently used or frequently switched between. Bilinguals who use both languages more frequently were found to have an advantage of better mixing costs compared to those that used only a single language frequently (Yow & Li, 2015).

In another study, Prior and Gollan (2011) directly compared monolinguals with bilinguals who frequently switch languages and bilinguals who infrequently switch languages. Only the bilinguals who frequently switched languages were identified to have an advantage in task switching, indicating that the bilingual advantage is more about current use of multiple languages rather than early acquisition. Soveri et al. (2011) similarly compared monolinguals with Finnish-Swedish bilinguals who had all learned both languages at an early age, regularly used both languages throughout their daily lives and had the same level of proficiency across languages. The researchers tested the groups on a Simon task, a Flanker task, and the number-letter switch task from Rogers and Monsell (1995). Using a regression model, the AoA predicted a smaller Simon effect but did not have any significance to task switching. For the task switching experiment, Soveri et al. (2011) found that there was no single predictor that could account for the variance of the mixing cost of reaction time, but the amount of language switching predicted smaller mixing costs in terms of errors (Soveri et al., 2011). Tse and Altarriba (2015) also added support to the findings that higher second language proficiency results in better task switching abilities by identifying that participants have smaller local switch costs on a Stroop switch task. Unfortunately, none of these papers could directly compare bilinguals that had learned a second language later and regularly use it, and bilinguals that had learned the second language at an early age.

Since proficiency of a second language and frequency of use are often highly correlated, there has been very little research into the area of attempting to compare proficiency with the frequency that a second language is used. One exception is a study by Verreyt et al. (2016). The researchers compared participants' performances on a flanker and a Simon task. Verreyt et al. found that proficient bilinguals that switched very often between languages outperformed both subjects who switched frequently but were not proficient and subjects that were proficient, but did not frequently switch (Verreyt et al., 2016).

1.4. Summary

The underlying reason as to why bilinguals appear to have a cognitive advantage is still not clear, and by the evidence above, it is also not clear how this advantage emerges over time. Further research is needed to explain how the bilingual advantage emerges over time, and particularly how there may be differences between those that learned a second language from an early age compared with those that learned a second language at an older age taking into account their proficiency of the language. Having some idea of the differences between these different groups may provide a deeper understanding of whether the bilingual advantage is really just a practice effect, or due to early cognitive development. If the bilingual advantage is merely a practice effect, it would mean that anyone could obtain this advantage, and there may be other, more efficient ways of gaining this practice effect.

1.5. Current Study

Based on the review of the bilingual advantage, there was still an open question about whether the advantage is a result of the second language being acquired at an early age or whether it is purely based on fluency of the second language acquired. The current study aimed to determine how the bilingual advantage may emerge differently depending on when one learned a second language and the proficiency one has of that language. Video game research has indicated sufficient practice provides advantages to cognitive control to reduce switch costs, even in the short term (Hartanto et al., 2016; Strobach et al., 2012). Additionally, other research has shown that media multitasking may also provide a similar advantage in lowering switch costs (Alzahabi & Becker, 2013). There is evidence that language acquisition at a later age can lead to improvements in cognitive control (Vega-Mendoza et al., 2015), and that the bilingual advantage is more associated with language usage rather than AoA (Prior & Gollan, 2011; Soveri et al., 2011; Tse & Altarriba, 2015; Verreyt et al., 2016; Yow & Li, 2015). Thus, it is hypothesized that the bilingual advantage may be a result of a practice effect that can generally be learned. However, research has not provided strong evidence to understand whether the bilingual advantage is merely a practice effect, a separate cognitive improvement that can only be learned at an early age, or a combination of the two.

The amount a person feels comfortable with a second language has two primary confounding factors, the age they acquired the second language, and their fluency of the language. Studies have already given an indication that regular use of a language is a better predictor of a bilingual advantage than AoA alone (Yow & Li, 2015). However, these studies failed to compare those that learned the language from an early age to become proficient with those that learned a second language at a late age to become similarly proficient. Therefore, the participants were categorized by AoA, whether they learned the language at an early age (7 or younger) or a later age (8 or older). Secondly, within these two groups, the participants were split by their fluency of the language, categorized as either lower or higher fluency using a median split.

In addition to AoA and fluency, different cue-target intervals (CTIs) have been shown to affect switch costs by providing participants preparation time when switching between tasks (Meiran, 1996). The bilingual advantage has previously been considered a cognitive ability to reconfigure tasks quicker, meaning that bilinguals should require less preparation time, and so varying CTI should have less of an effect on fluent bilinguals. On the other hand, if the bilingual advantage is primarily a practice effect through years of proficient use, fluency in combination with manipulation of CTI would provide an even greater improvement to reducing switch costs. Therefore, this study included a manipulation of CTI to provide a better understanding of how the bilingual advantage emerges, and whether the bilingual advantage is purely a practice effect or whether it relies on cognitive improvements that occur in early childhood.

Practice with a specific task can also reduce the switch cost for all participants. Thus, the study also included the variable of Block Half to examine performance in the first versus second half of a block. Finally, Crosstalk was examined by including blocks where there was crosstalk between the stimulus dimensions or no crosstalk between stimulus dimensions to examine the effects of interference on task-switching of bilinguals. The overall design for this study was a 2 (AoA: 7 or younger vs. 8 or older) x 2 (Fluency: lower vs. higher) x 2 (CTI: short vs. long) x 2

(Crosstalk: Crosstalk vs. No Crosstalk) x 2 (Task: Shape vs. Color) x 2 (Trial Type: Switch vs. Non-switch) x 2 (Block Half: 1st Half vs. 2nd Half) mixed design.

1.6. Hypotheses

It was expected that the results from the present study would show effects of task-switching (i.e., trial type), CTI, Crosstalk and Block half, which have been demonstrated in the task-switching literature. Below, three hypotheses relevant to the factors of AoA and fluency are made.

Hypothesis 1: *Early learners have an advantage over late learners.*

Participants who acquired a second language before 7 years of age (i.e., early learners) was expected to have lower switch costs than participants who acquired a second language after 7 years of age (i.e., late learners). This advantage for early learners is due to multiple years of added practice from switching between their first and second languages.

Hypothesis 2: *Greater fluency will lead to a larger bilingual advantage, resulting in smaller switch costs.*

Past research has shown that proficiency of a second language is a strong indicator of the bilingual advantage, lowering switching costs, so there should be a main effect of fluency.

Hypothesis 3: *There will be an interaction between CTI and fluency.*

Since greater fluency means that one can more easily switch between languages, it also means that the person needs less time to prepare to switch between languages. Similarly, the same effect may be seen in task switching. The participants in the higher fluency group may perform better than the lower fluency group in the short CTI condition, but this advantage may decrease in the long CTI condition when all participants have more time to prepare.

In addition to the above hypotheses, the present study will help answer the general research question of how does AoA and fluency influence the task-switching performance of bilinguals by looking at whether these two factors interact.

CHAPTER 2

METHOD

2.1. Participants

English-Spanish participants were originally recruited through the SONA systems participant pool, consisting of students from Psychology 100 courses. However, due to low sign-up rates over a month or recruitment, additional participants were recruited through Amazon Mechanical Turk (MTurk) and with snowball sampling (i.e., word-of-mouth recruitment). Recruitment through SONA was open to students who were currently enrolled in PSY 100 at California State University, Long Beach (CSULB), and were at least 18 years old.

Participation in this study was limited to participants who self-identify as bilingual Spanish and English speakers who learned their second language at an early (7 years of age or younger) or late (8 or older) age. Participants could have had either English or Spanish language as their first language as the study only involved non-verbal stimuli (Prior & MacWhinney, 2010). The age at which participants learned their second language was verified with survey data filled out by each participant, and 8 participants had to be reclassified to the early AoA group, and 1 to the late AoA group. For the early AoA group, 49 participants were obtained from SONA. For the late AoA group, 9 participants were found from SONA, 2 from MTurk, and 24 through snowball sampling for a total of 35 participants in that group. Four participants were excluded for not self-identifying as Spanish-English bilinguals (2 English monolinguals, 1 English-Swahili bilingual, and one multi-lingual participant that specified Spanish as their 4th language) and 21 participants were excluded for overall error rates greater than 15%. This left 37 participants in the early AoA group and 21 in the late AoA group (see Table 1 for demographics and Table 2 for participant subject pools).

All participants were required to use a personal computer with an internet browser other than Safari. The Safari browser does not support full screen experiments using keyboard input with the experimental platform that was used for the study. Participants from SONA received course credit for their participation through the SONA system and participants from MTurk were compensated $3 for their participation. Participants from snowball sampling were not compensated.

2.2. Design

This study employed a 2 (AoA: 7 or younger vs. 8 or older) x 2 (Fluency: lower vs. higher) x 2 (CTI: short vs. long) x 2 (Crosstalk: Crosstalk vs. No Crosstalk) x 2 (Task: Shape vs. Color) x 2 (Trial Type: Switch vs. Non-switch) x 2 (Block Half: 1st Half vs. 2nd Half) mixed design. AoA was a between-subjects variable along with fluency. CTI, Crosstalk, Task, Trial Type and Block Half were within subject's variables. The dependent variables for this study were reaction time and error rate.

2.3. Materials

The experiment was programmed on PsyToolkit (Stoet, 2010, 2017), such that the subject required a computer with an internet connection and browser other than Safari. Since the experiment required keyboard input, and the experiment could not be performed using Safari, which does not allow keyboard input in full screen mode. The PsyToolkit program was embedded within a PsyToolkit survey that was filled out by participants. PsyToolkit provided the instructions and tasks that were performed by participants, and recorded responses.

2.3.1. Task Switching Task

The tasks involved choosing between a color or shape of a stimulus. Both crosstalk and no-crosstalk blocks were used in the experiment. In the crosstalk blocks, the tasks showed a colored shape, a circle or square, filled either in yellow or blue. In the no-crosstalk blocks, the color task was a series of uppercase H's formed to prevent any confusion with the existing shapes, removing any crosstalk from the shape task and was similarly either yellow or blue font. For the shape task, the stimulus were white squares or circles to remove the color dimension in the no crosstalk blocks. Both tasks involved pressing either "x" or "m" keys on the participant's keyboard. The response to the task was congruent on half of the trials and incongruent on the other half.

2.3.2. Survey

A survey (see Appendix A) was given to participants at the end of the experiment. It consisted of questions that collected demographic data, including gender and ethnicity. In order to check if the participants' task switching results could be influenced by other activities, the survey also included questions that requested information on research areas previously mentioned that may have lowered switch costs for exploratory purposes. For example, the survey asked if the participant played fast paced or action video games, and if so, how frequently.

2.3.3. Language Experience Questionnaire (LEAP-Q)

The LEAP-Q questionnaire (Appendix B) was designed to assess language profiles in bilinguals (Marian et al., 2007). The questionnaire consists of 23 questions, split into three sections. The first section of the questionnaire retrieves general information about the languages the participant knows (the study used a modified version of the first section, deleting questions regarding immigration status, birthdate, and other questions not relevant to the study), and how frequently they are used. The second and third section of the questionnaire have identical questions for determining the participant's fluency of their first and second languages, one section per language. The LEAP-Q has been found to be both internally valid and has established criterion-based validity (Marian et al., 2007). That is, Marian et al. (2007) found that Cronbach's alpha for each factor separately to be .31 to .92, which they indicated as suggesting overall consistency of components within each factor. The LEAP-Q has been found to be a quick and reliable form of assessing bilingual and multilanguage subjects (Kaushanskaya et al., 2020).

To distinguish low and high fluency groups, a fluency score was computed from the LEAP-Q (Marian et al., 2007) questionnaire by taking a composite score of participant's self-assessed speaking, listening, reading, and writing scores in their second-most dominant language, similar to existing studies (Kaushanskaya et al., 2020). The composite score was used to perform a median split of both AoA groups to determine the participants in the high and low fluency groups. The range of the fluency scores was 2.75 to 11. The median score was 8.5, which was used as the cutoff for categorizing participants as low or high fluency. For the early AoA group, the median fluency score of participants was 8.5 and for the late AoA group the median fluency score was 8.

2.4. Procedure

Students at CSULB signed up for the subject pool through the SONA system. Amazon MTurk workers signed up to take the study through the MTurk platform, and participants recruited through snowball sampling signed up for the study by clicking on a hyperlink embedded in a recruitment email. The experiment was split into two separate programs in order to recruit participants for the different AoA groups within this study. For the 3 subject pools, each subject would be able to choose from 1 of 2 experiments based on when they acquired their second language. For both experiments, there was a criterion specifying that the study was only for participants who self-identify as English-Spanish bilinguals. One experiment added a criterion that the participant learned their second language at 7 years of age or earlier, and the second experiment added a criterion that the participant learned their second language at 8 years of age or older. Both experiments were otherwise identical. Therefore, only the general experiment is described below.

During the experiment, all instructions were provided on screen to the participants. The task switching experiment consisted of two tasks: a shape task and a color task. For each trial (see Figure 1), a fixation cross appeared for 150 ms, then 500 ms later a cue appeared onscreen indicating whether the current task was the color task or the shape task. The cue stayed onscreen for either a short (600 ms) or long (1350 ms) CTI prior to presenting the target. For the crosstalk and no-crosstalk conditions, the targets were displayed in separate blocks, those with crosstalk and those without crosstalk. The user was tasked with selecting the appropriate response based on whether they were given the shape or the color task by a cue. When performing the color task, the participant needed to press the first key for yellow and the second key for blue for the correct response. In the shape task, the participant needed to press the first key for Circle and the second key for Square for the correct response. The mapping of response to stimulus was counterbalanced across participants, so that half the participant used ‘x’ as the first key and ‘m’ as the second key, and the other half of the participants had these keys switched. When the participant responded, the target disappeared from the screen.

If the participant specified the correct response, the next trial began 1000 ms after the response. If the participant specified the incorrect response, or did not answer within 3000 ms, a response showed that the answer was incorrect or too slow and a delay of 1500 ms was used prior to the next trial. Each participant performed 16 mixed-task practice trials before the test blocks. After the practice block, each participant performed 4 mixed-task blocks that varied in terms of the presence of crosstalk and length of the CTI, each including 96 trials. The four blocks

were: crosstalk-short CTI, crosstalk-long CTI, no crosstalk-short CTI and no crosstalk-long CTI, and the order in which participants received the blocks were counterbalanced across participants. Within each block, the color (C) and shape (S) tasks were performed by alternating runs of two pairs (i.e., CCSSCCSSCC…), with the starting task counterbalanced across participants.
After participants completed all four task-switching blocks, the participants filled out a questionnaire regarding demographic information, and a LEAP-Q to retrieve more detailed information regarding their proficiency of each language.

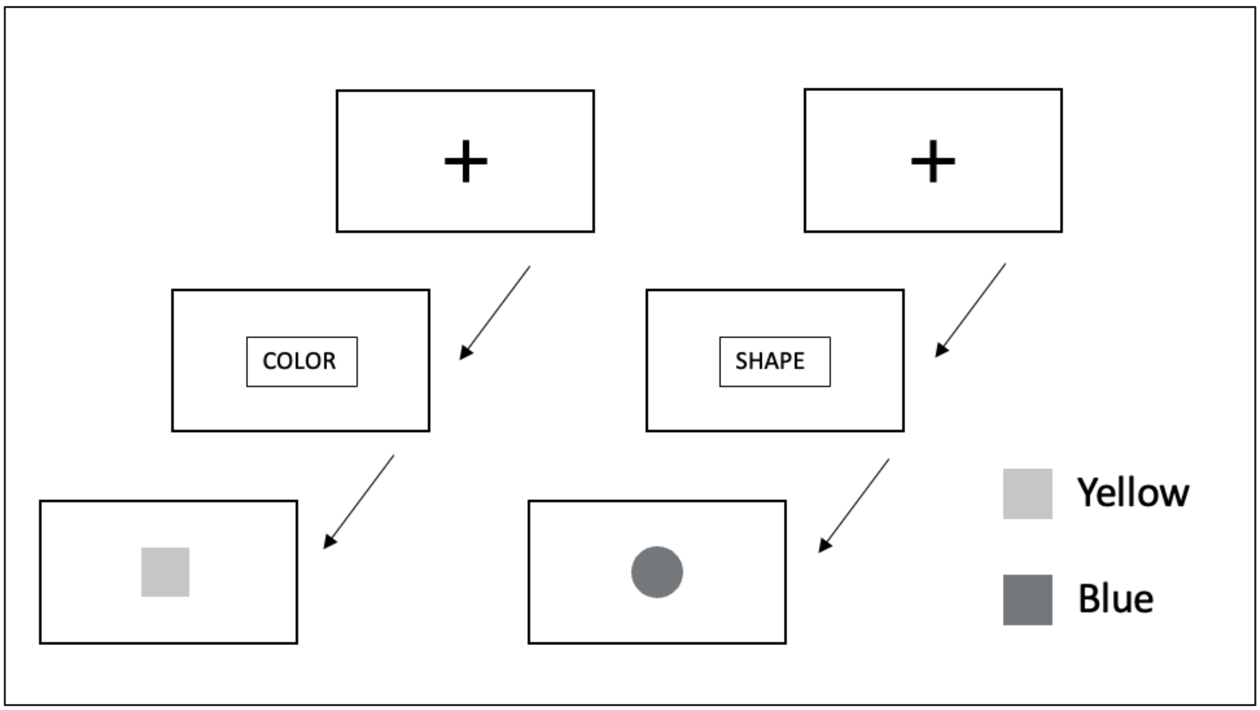

FIGURE 1. Illustration of the trial sequence for the shape and color tasks in the crosstalk condition.

CHAPTER 3

RESULTS

This study only examined local switch costs, defined as the difference of reaction time and error rate between switch and non-switch trials within a block. An interference effect is defined as the difference of reaction time and error rate between crosstalk and no-crosstalk trials. Preparation effect is defined as the difference of reaction time and error rate between short and long CTI. Practice effect is defined as the difference of reaction time and error rate between the first and second half of the blocks. Huynh-Feldt corrections were applied as necessary due to the small sample sizes.

3.1. Reaction Time

Mean reaction times were submitted to a 2 (AoA: 7 or younger vs. 8 or older) x 2 (Fluency: lower vs. higher) x 2 (CTI: short vs. long) x 2 (Crosstalk: Crosstalk vs. No Crosstalk) x 2 (Task: Shape vs. Color) x 2 (Trial Type: Switch vs. Non-switch) x 2 (Block Half: 1st Half vs. 2nd Half) factorial ANOVAs. The means for each condition are listed in Table 3.

There was a main effect of Trial Type, $F(1, 54) = 79.17$, $MSE = 21511.02$, $p < .001$, $\eta_p^2 = .595$, with response times being 63.08 ms slower on switch trials (M = 832.13) than non-switching trials (M = 769.05). The main effect of Trial Type was qualified by an interaction with Task, $F(1, 54) = 7.55$, $MSE = 13962.916$, $p = .008$, $\eta_p^2 = .123$, with the switch cost for the shape task (MD = 78.78 ms) being greater than that for the color task (MD = 47.491 ms).

There was a main effect of Crosstalk, $F(1, 54) = 37.59$, $MSE = 160417.08$, $p < .001$, $\eta_p^2 = .410$, with responding being slowed by 119 ms on trials when crosstalk was present (M = 859.94 ms) than when it was not (M = 741.24 ms).

The main effects for Crosstalk and Trial Type were both qualified by an interaction between the two variables, $F(1, 54) = 28.92$, $MSE = 22897.69$, $p < .001$, $\eta_p^2 = .349$. The switch costs were lower in the crosstalk condition (MD = 23.75 ms) compared to the no-crosstalk condition (MD = 102.42 ms).

There was a main effect of CTI, $F(1, 54) = 7.26$, $MSE = 92927.32$, $p = .009$, $\eta_p^2 = .118$, with response times being 40 ms slower at the long CTI (M = 820.44 ms) than short (M = 780.74 ms) CTI.

The main effect of CTI was qualified by a significant interaction with Task and fluency, $F(1, 54) = 5.23$, $MSE = 10111$, $p = .026$, $\eta_p^2 = .088$. For the color task, the difference in reaction time between short and long CTI for the low fluency group (MD = 73 ms) was larger than that for the high fluency group (MD = 21 ms). For the shape task the difference in reaction time between short and long CTI was similar for the low (MD = 36 ms) and high (MD = 27 ms) fluency groups.

The main effects for Crosstalk and CTI were both qualified by an interaction between both variables and Task, $F(1, 54) = 13.16$, $MSE = 11456.71$, $p < .001$, $\eta_p^2 = .196$. When performing the color task, the crosstalk interference effect was 26.56 ms lower for short CTI (MD = 102.05) compared to long CTI (MD = 128.61), whereas in the shape task the crosstalk interference effect was 48.52 ms greater for short CTI (MD = 146.34) compared to long CTI (MD = 97.82).

There was a main effect of Block Half, $F(1, 54) = 21.89$, $MSE = 31164.21$, $p < .001$, $\eta_p^2 = .288$, with response times being 39.926 ms slower on the first half of blocks (M=820.55) than the second half (M=780.63).

The main effect of Block Half was qualified by a significant interaction with AoA, $F(1, 54) = 5.67$, $MSE = 31164.21$, $p = .021$, $\eta_p^2 = .095$. The late AoA participants showed a larger reduction in reaction time (MD = 60 ms) in the second half of the block compared with early AoA participants (MD = 20 ms).

The interaction between AoA and Block Half was modified by a significant 3-way interaction of those variables with fluency, $F(1, 54) = 4.62$, $MSE = 31164.21$, $p = .036$, $\eta_p^2 = .079$, see Figure 2. All groups showed a reduction in reaction time for the second half of the blocks (reductions of 39, 77 and 42 ms, respectively for the Early AoA-High fluency; Late AoA-Low fluency and Late AoA-High fluency groups), except the Early AoA-Low fluency group, which had similar reaction times across both halves of the blocks.

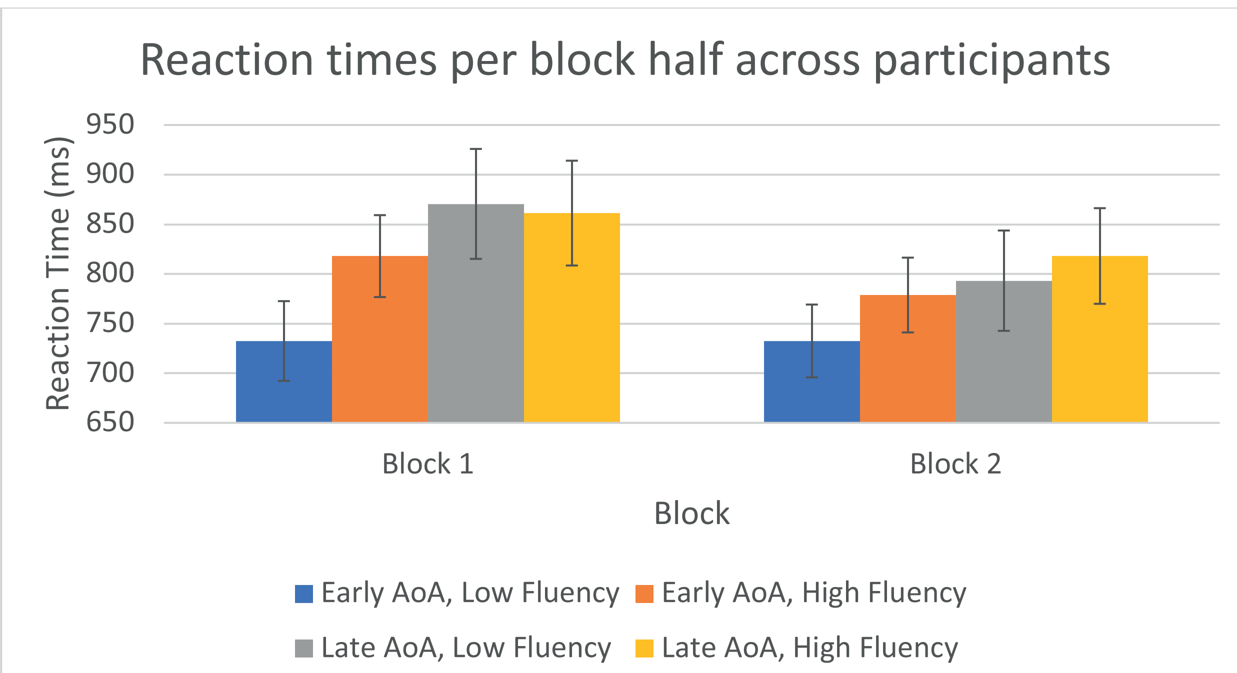

FIGURE 2. Reactions of all groups across blocks.

The main effects for CTI and Block Half were both qualified by an interaction between the two variables, $F(1, 54) = 4.70$, $MSE = 32798.51$, $p = .035$, $\eta_p^2 = .080$, with the difference between short and long CTI being larger for the first half (MD = 58.70 ms) than second half (MD = 20.72) of the blocks.

The interaction between CTI and Block Half was qualified by a 3-way interaction of both variables and Crosstalk, $F(1, 54) = 4.29$, $MSE = 31973.50$, $p = .043$, $\eta_p^2 = .074$, see Figure 3. There was a practice effect for both short (MD = 56.84 ms) and long (MD = 54.67 ms) CTI in the no-crosstalk condition. However, in the crosstalk condition, the practice effect was evident for the short CTI condition (MD = 60.97 ms) but not the long one (MD = -12.78 ms).

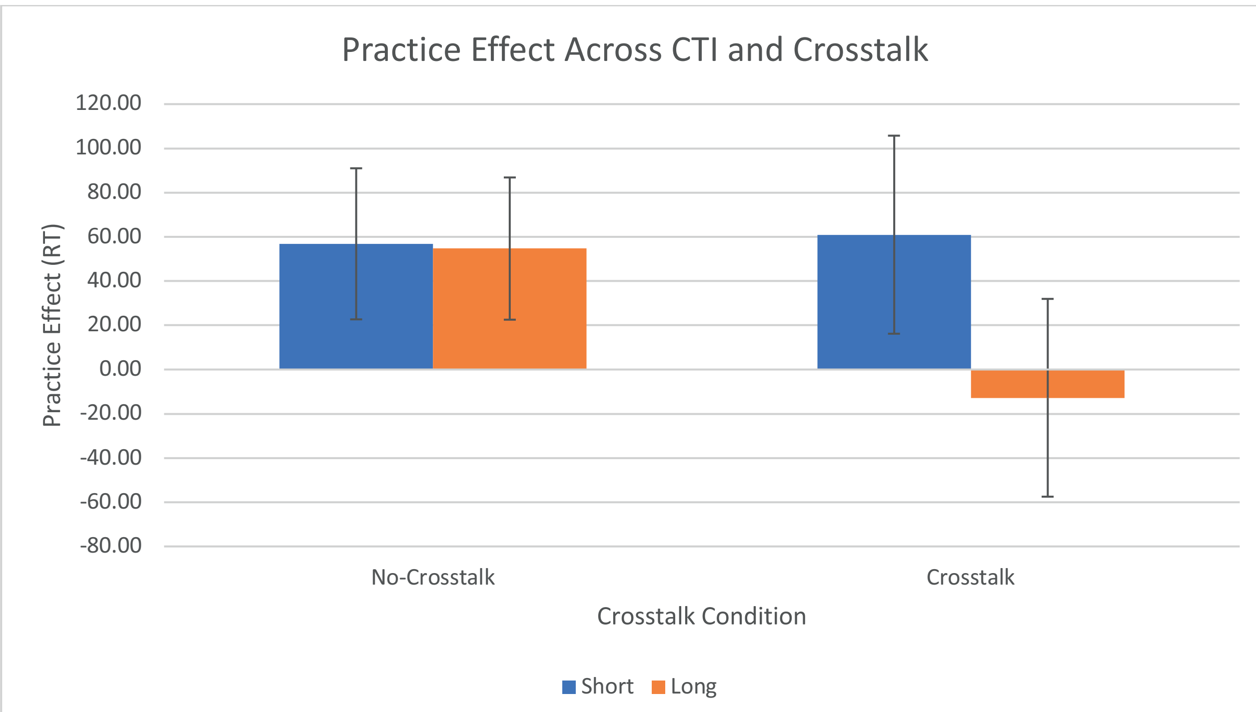

FIGURE 3. Interaction between CTI, block half and crosstalk.

There was also a 4-way interaction between Task, Crosstalk, CTI and Block Half, $F(1, 54) = 8.62$, $MSE = 9019.464$, $p = .005$, $\eta_p^2 = .138$, see Figures 4 and 5. When no crosstalk was present, the practice effect for the color and shape tasks was the same at short CTI (MD = 54.55 ms and MD = 59.12 ms, respectively), but at the long CTI the practice effect was smaller for the color task (MD = 30.81 ms) and larger for the shape task (MD = 78.56 ms). However, when crosstalk was present and the CTI was short, the practice effect was larger for the shape task (MD = 76.29 ms) than the color (MD = 45.64 ms) task. When crosstalk was present and the CTI was long, there was no practice effect. Responses were only 4.22 ms faster on the second half than the first half when the task was color and in fact, responses were 29.79 ms slower in the second half when the task was shape.

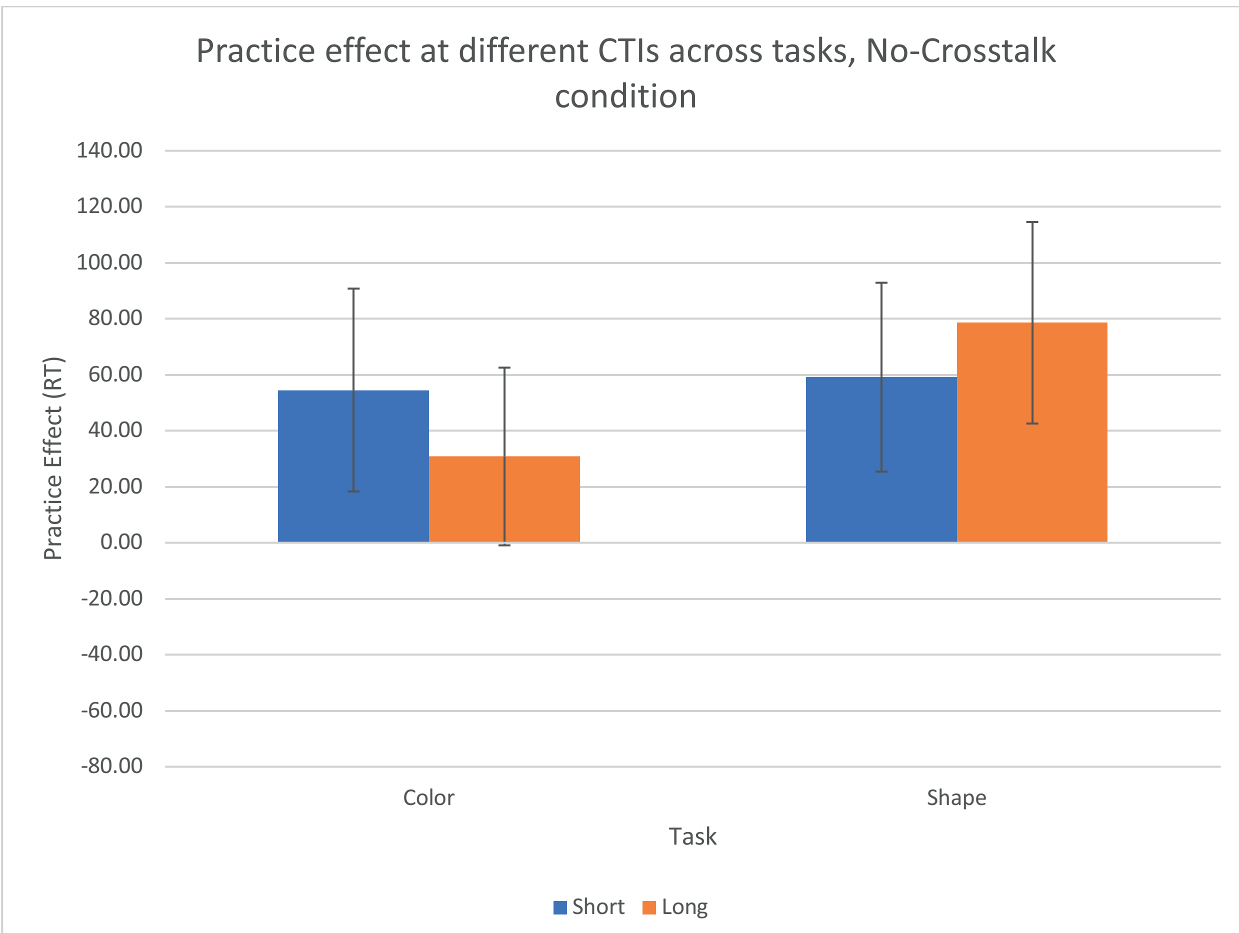

FIGURE 4. Practice effects across CTI and task in the no-crosstalk condition.

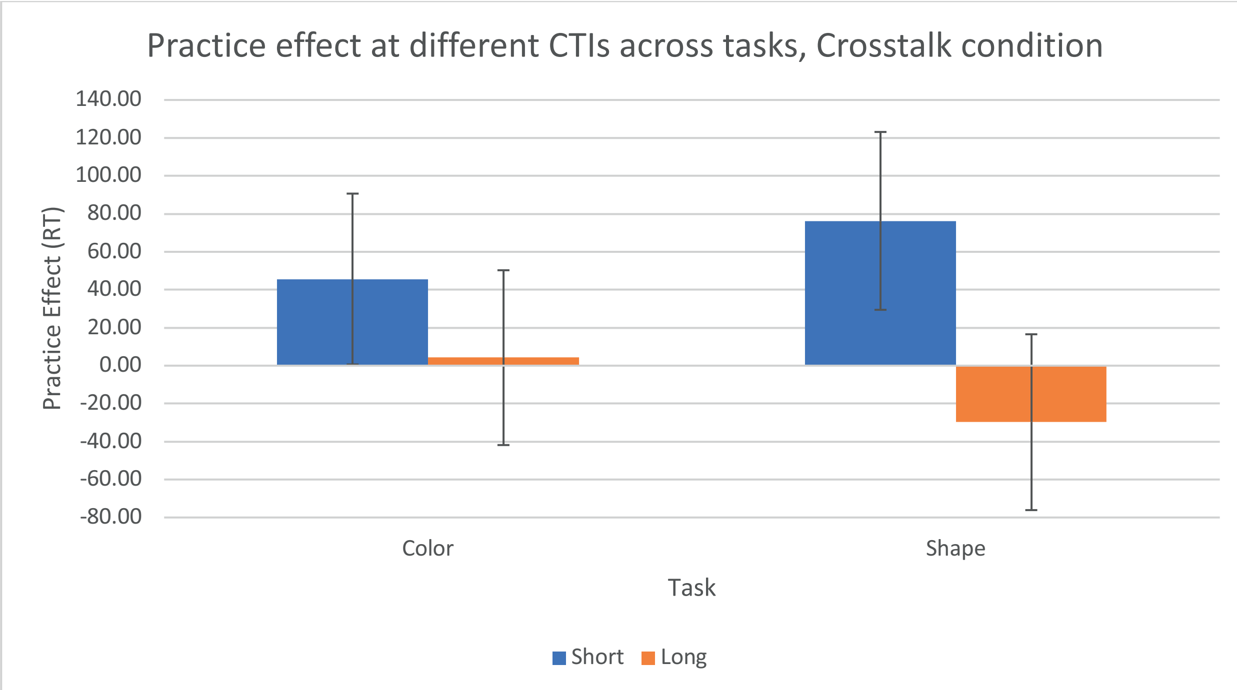

FIGURE 5. Practice effects across CTI and task in crosstalk condition.

There was a significant 5-way interaction of Task, CTI, Trial Type, AoA, and fluency, $F(1, 54) = 6.37$, $MSE = 13050.48$, $p = .015$, $\eta_p^2 = .106$, see Figure 6 and Figure 7. For the color task, at the short CTI, the switch cost was smallest for the early AoA-low fluency (MD = 17 ms) and late AoA-high fluency (MD = 18 ms) groups, intermediate for the late AoA-low fluency (MD = 38 ms) and largest for the early AoA-high fluency (MD = 92 ms) group. At the long CTI, the switch cost for the color task was smallest for the late AoA-low fluency (MD = 23 ms), intermediate for the early AoA-low fluency (MD = 47 ms) and early AoA-high fluency (MD = 55 ms) groups, and largest for the late AoA-high fluency (MD = 89 ms) group. For the shape task, at the short CTI, the switch cost was smallest for the early AoA-low fluency (MD = 60 ms), intermediate for the late AoA-low fluency (MD = 72 ms) and early AoA-high fluency (MD = 86 ms) groups, and largest for the late AoA-high fluency (MD = 97 ms) group. At the long CTI, the switch cost for the shape task was smallest for the early AoA-low fluency (MD = 50 ms), intermediate for the late AoA-high fluency (MD = 72 ms) and early AoA-high fluency (MD = 87 ms) groups, and largest for the late AoA-low fluency (MD = 106 ms) group.

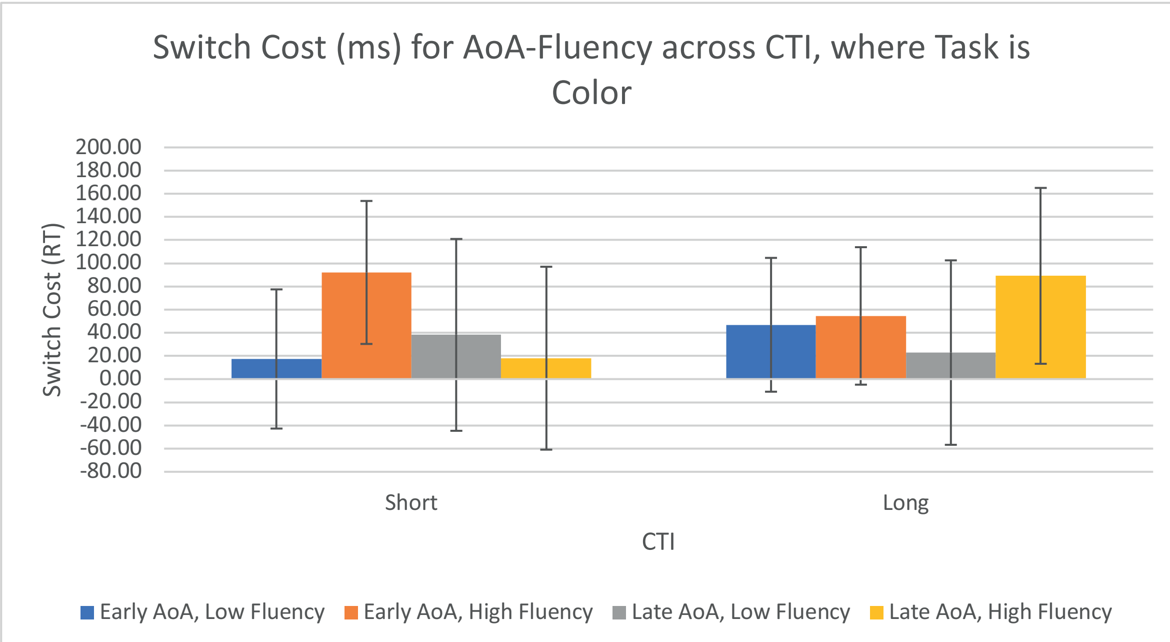

FIGURE 6. Switch costs for the color task across CTI conditions.

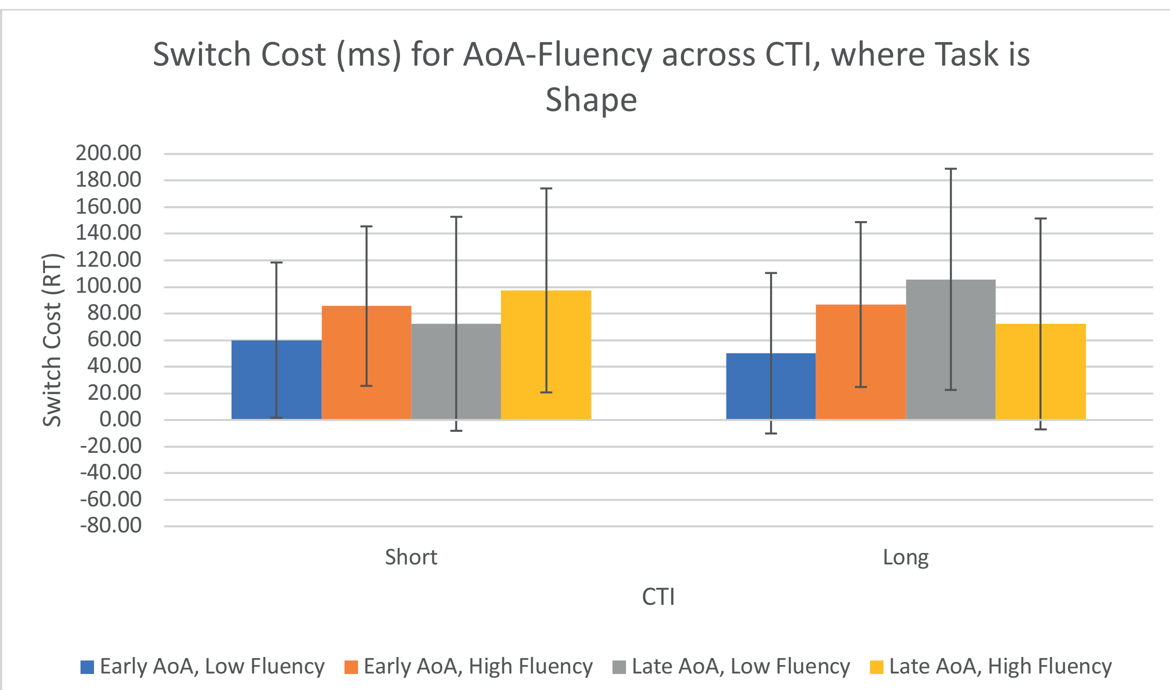

FIGURE 7. Switch costs for the shape task across CTI conditions.

There was a significant 5-way interaction of Task, Crosstalk, Trial Type, AoA, and fluency, $F(1, 54) = 6.31$, MSE =9900.04, $p = .015$, $\eta_p^2 = .105$, see Figure 8 and Figure 9. For the color task, when no crosstalk was present, the switch cost was smallest for the late AoA-low fluency (MD = 58.2 ms) and early AoA-low fluency (MD = 61.33 ms) groups, intermediate for the early AoA-high fluency (MD = 100.81 ms) and largest for the late AoA-high fluency (MD = 135.86 ms) group. When crosstalk was present, no switch costs were observed for the color task for the late AoA-high fluency (MD = -28.68 ms), late AoA-low fluency (MD = 2.85 ms), and early AoA-low fluency (MD = 2.93 ms) groups, but a switch cost was obtained for the early AoA-high fluency (MD = 45.81 ms) group. For the shape task, when no crosstalk was present, the switch cost was smallest for the early AoA-low fluency (MD = 82.88 ms), intermediate for the late AoA-high fluency (MD = 110.86 ms) group and largest for the early AoA-high fluency (MD = 130.38 ms) and late AoA-low fluency (MD = 139 ms) groups. When crosstalk was present, the switch cost for the shape task was smallest for the early AoA-low fluency (MD = 27.33 ms) group, intermediate for the late AoA-low fluency (MD = 39.03 ms) and early AoA-high fluency (MD = 41.99 ms) groups, and largest for the late AoA-high fluency (MD = 58.75 ms) group.

3.2. Error Rate

Mean error rates were submitted to 2 (AoA: 7 or younger vs. 8 or older) x 2 (Fluency: lower vs. higher) x 2 (CTI: short vs. long) x 2 (Crosstalk: Crosstalk vs. No Crosstalk) x 2 (Task: Shape vs. Color) x 2 (Trial Type: Switch vs. Non-switch) x 2 (Block Half: 1st Half vs. 2nd Half) factorial ANOVAs. The means for each condition are listed in Table 4.

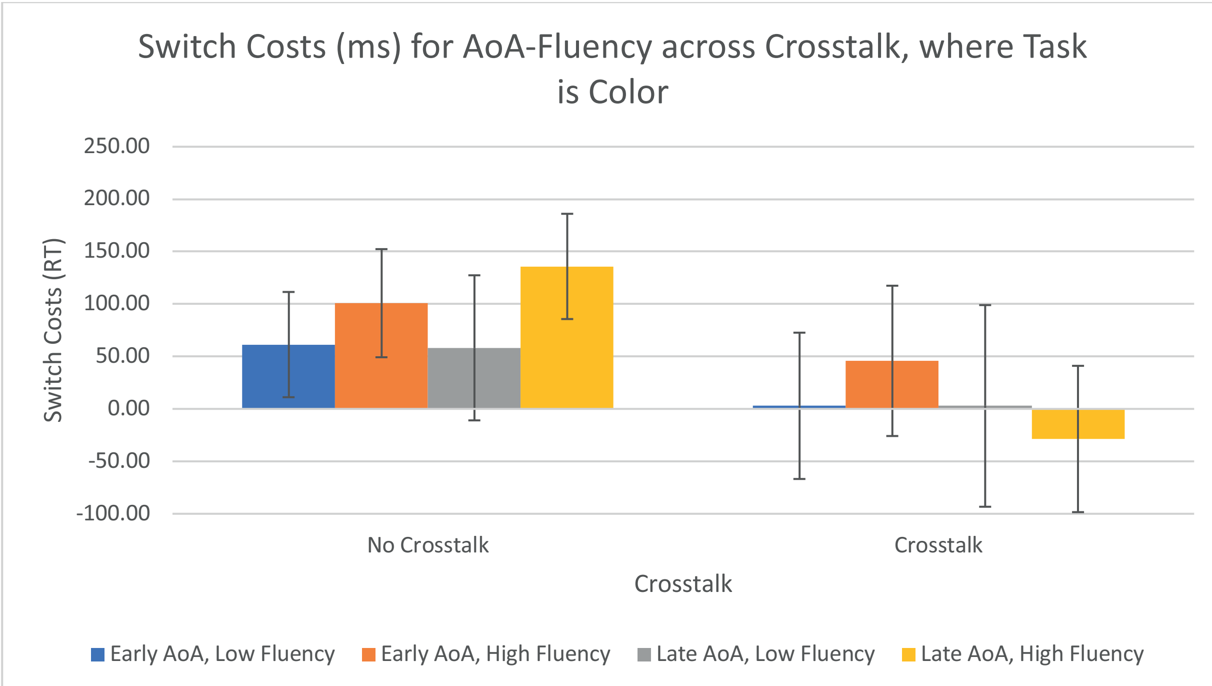

FIGURE 8. Switch costs for the color task across crosstalk conditions.

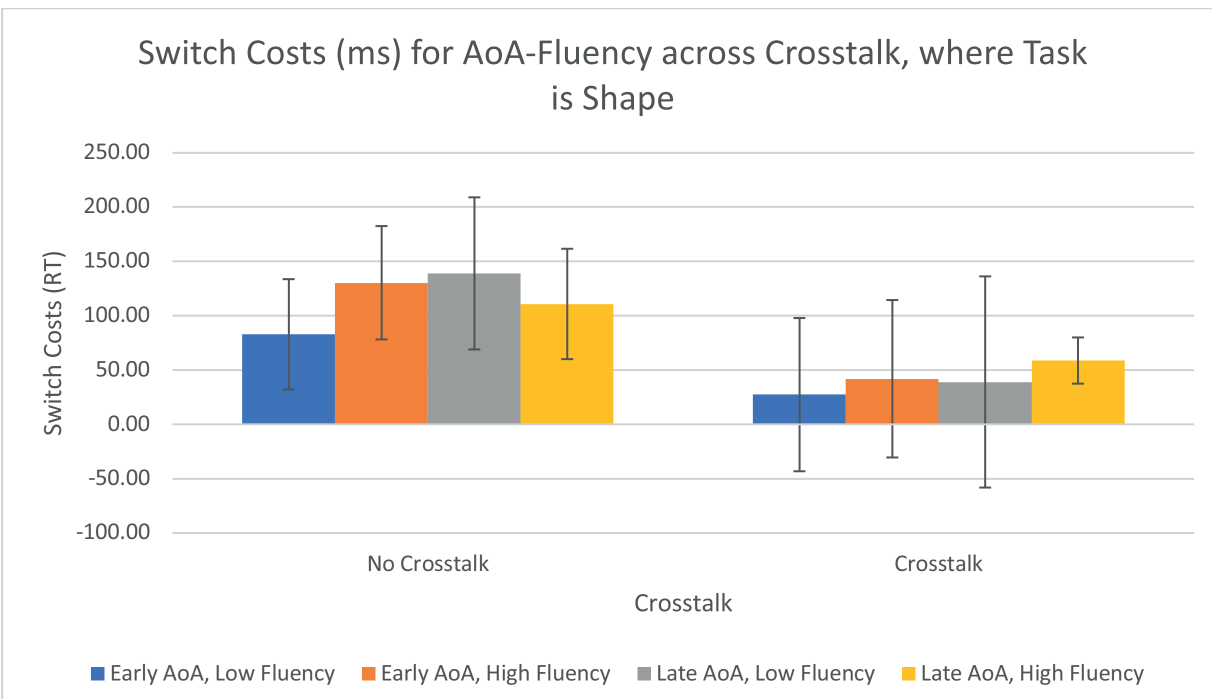

FIGURE 9. Switch costs for the shape task across crosstalk conditions.

There was a main effect of trial type, $F(1, 54) = 6.92$, $MSE = .009$, $p = .011$, $\eta_p^2 = .114$. The error rates were higher on switch trials (M = .054) compared to non-switch trials (M = .042).

There was a main effect of crosstalk, $F(1, 54) = 22.21$, $MSE = .014$, $p < .001$, $\eta_p^2 = .291$. Participants made more errors in the crosstalk condition (M = .062) than the no-crosstalk condition (M = .035).

There was a main effect of block half, $F(1, 54) = 17.75$, $MSE = .009$, $p < .001$, $\eta_p^2 = .247$, as participants had a lower error rate in block 2 (M = .039) compared to block 1 (M = .058).

The main effect of trial type was qualified by an interaction with task, $F(1, 54) = 4.98$, $MSE = .005$, $p = .030$, $\eta_p^2 = .084$. The switch cost was larger for the color task (MD = .02) compared to the shape task (MD = .005).

The main effects of crosstalk and trial type were qualified by an interaction between the 2 variables, $F(1, 54) = 66.53$, $MSE = .009$, $p < .001$, $\eta_p^2 = .552$. In the no-crosstalk condition, there was a switch cost (M = .049), but in the crosstalk condition, the error rate was lower on switch than nonswitch trials (MD = -0.024).

There was a significant 3-way interaction between task, crosstalk and CTI, $F(1, 54) = 5.86$, $MSE = .005$, $p = .019$, $\eta_p^2 = .098$, see Figure 10. The interference from crosstalk was smaller at the short CTI (MD = .02) than long CTI (MD = .033) for the color task, but the reverse pattern was evident for the shape task. For the shape task, interference from crosstalk was smaller at the long CTI (MD = .018) than short CTI (MD = .038).

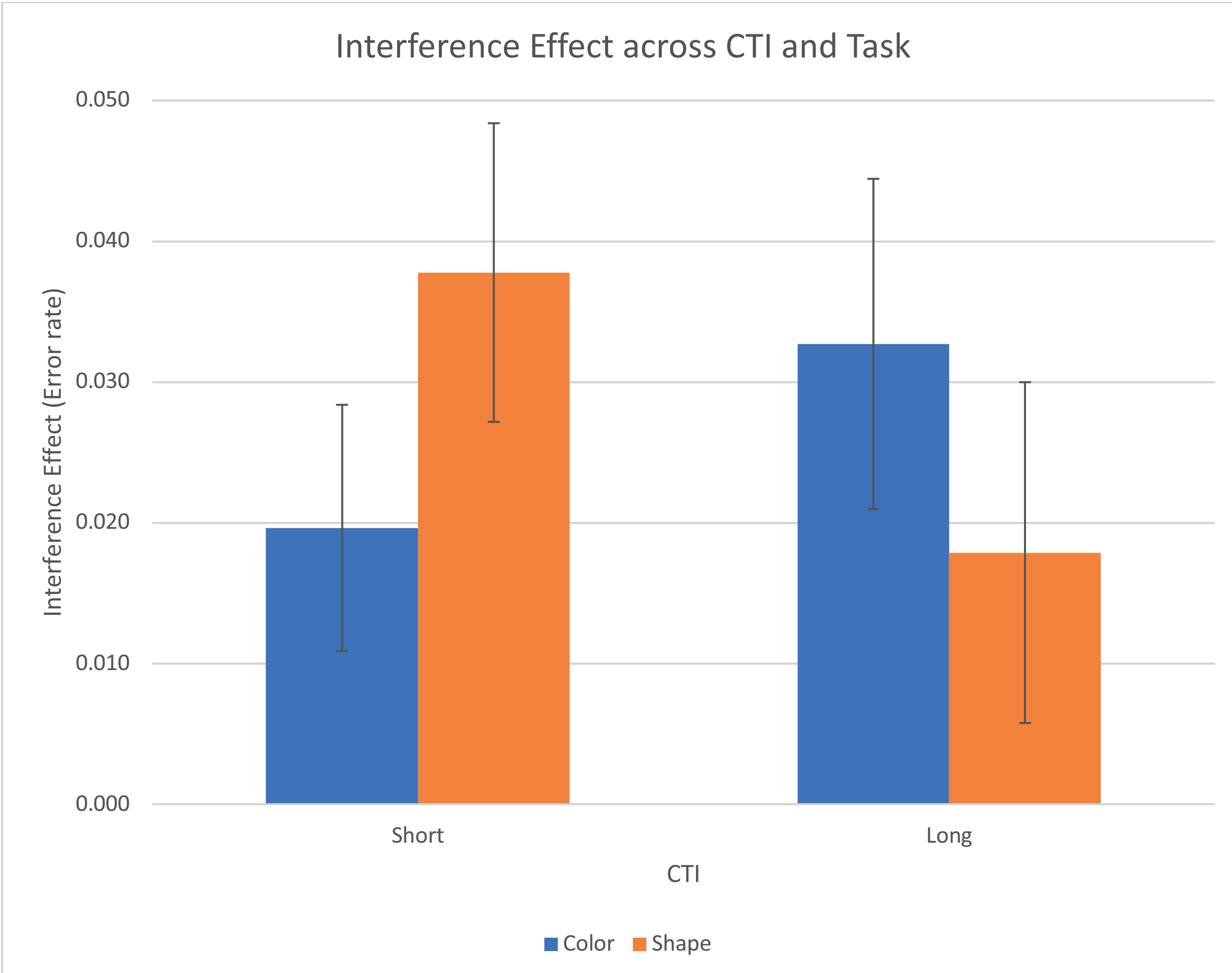

FIGURE 10. Error rate interaction between task, crosstalk and CTI.

The interaction between task, crosstalk and CTI was qualified by an interaction with trial type, $F(1, 54) = 7.82$, $MSE = .004$, $p = .007$, $\eta_p^2 = .127$, see Figure 11. For the color task, the switch cost was larger at the short CTI (MD = 0.063) than long CTI (MD = 0.043) when no crosstalk was present, whereas when crosstalk was present, the no switch costs were present at either the short CTI (MD = -0.016) or long CTI (MD = -0.009). For the shape task, short CTI and long CTI showed similar switch costs (MD = 0.04 and 0.049, respectively) in the no-crosstalk condition. Similar to the color task, in the crosstalk condition, the error rate was lower on switch trials than non-switch trials, with the difference being larger at the long CTI (MD = -0.052) compared to short CTI (-0.020).

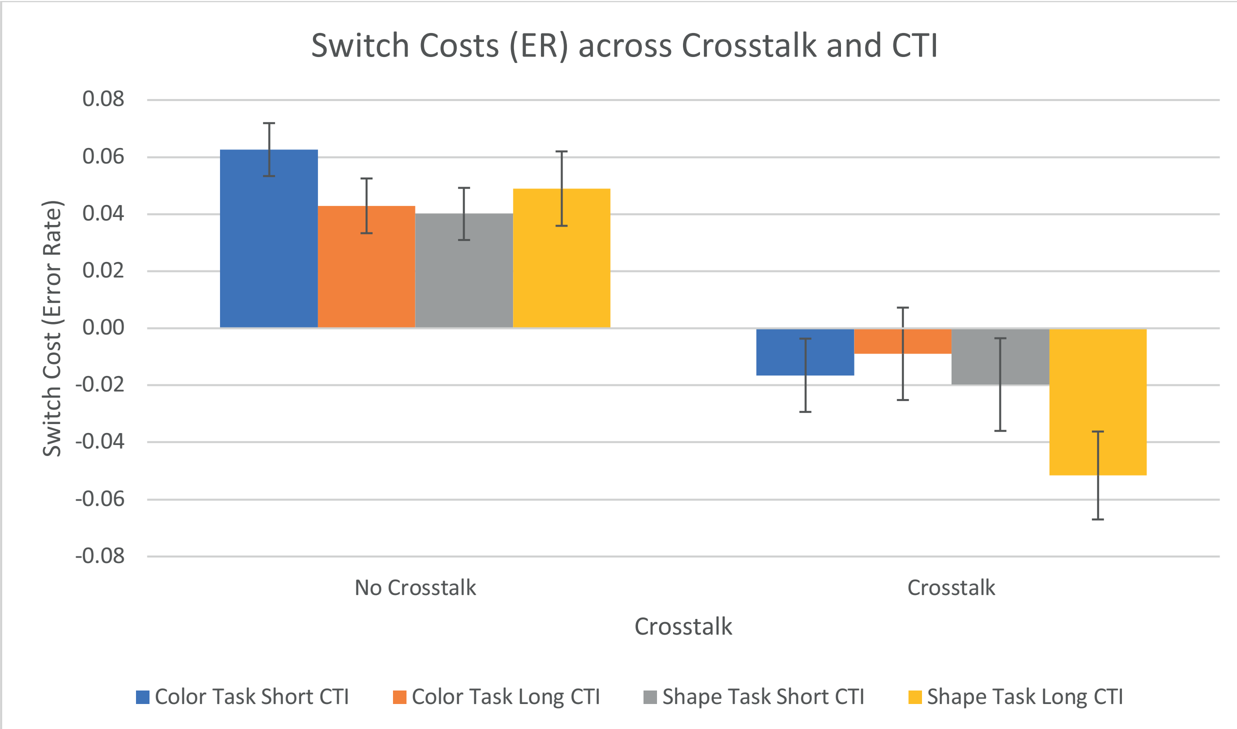

FIGURE 11. Switch costs for crosstalk conditions with short and long CTI across both tasks.

There was a significant 5-way interaction of Crosstalk, CTI, Trial Type, AoA, and fluency, $F(1, 54) = 7.78$, $MSE = .004$, $p = .007$, $\eta_p^2 = .126$, see Figure 12 and Figure 13. At the short CTI, the switch cost for the no-crosstalk condition was smallest for the early AoA-low fluency (MD = .04) group, intermediate for the late AoA-high fluency (MD = .05) and late AoA-low fluency (MD = .05) groups and largest for the early AoA-high fluency (MD = .06) group. At the long CTI, the switch cost for the no-crosstalk condition was smallest for the early AoA-high fluency (MD = .03) and late AoA-low fluency (MD = .03) groups, intermediate for the early AoA-low fluency (MD = .05), and largest for the late AoA-high fluency (MD = .06) group. At the short CTI for the crosstalk condition the late AoA-low fluency (MD = -0.03), early AoA-high fluency (MD = -0.026) and early AoA-low fluency (MD = -0.02) groups all performed better on switch trials than non-switch trials and only a small switch cost appeared in the late AoA-high fluency (MD = 0.004) group. At the long CTI for the crosstalk condition, all groups performed better on switch trials than non-switch trials. The smallest difference was obtained for the early AoA-high fluency (MD = -0.012) group, then for the early AoA-low fluency (MD = -0.033), late AoA-low fluency (MD = -0.038) and late AoA-high fluency (MD = -0.038) groups.

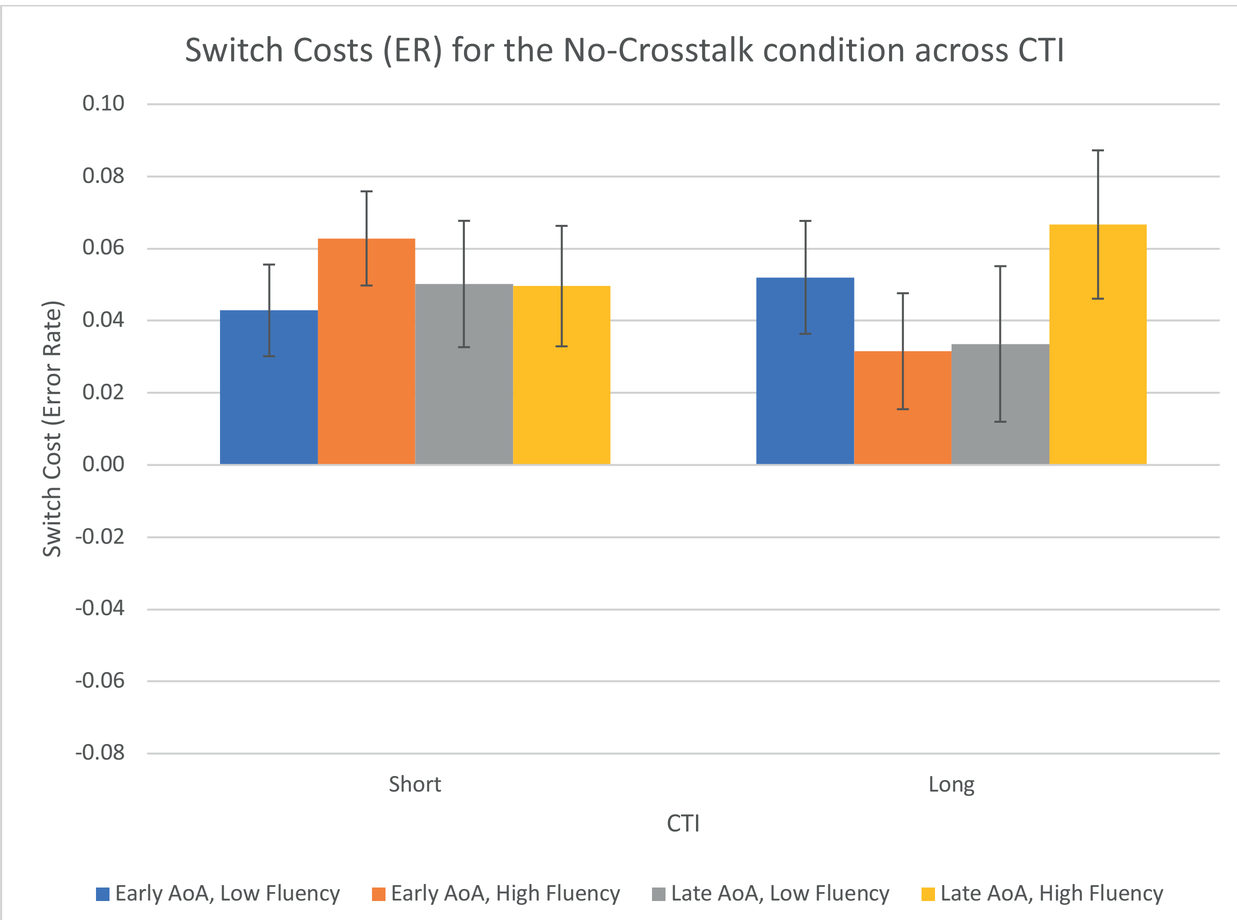

FIGURE 12. Switch costs for the no crosstalk condition across both CTIs.

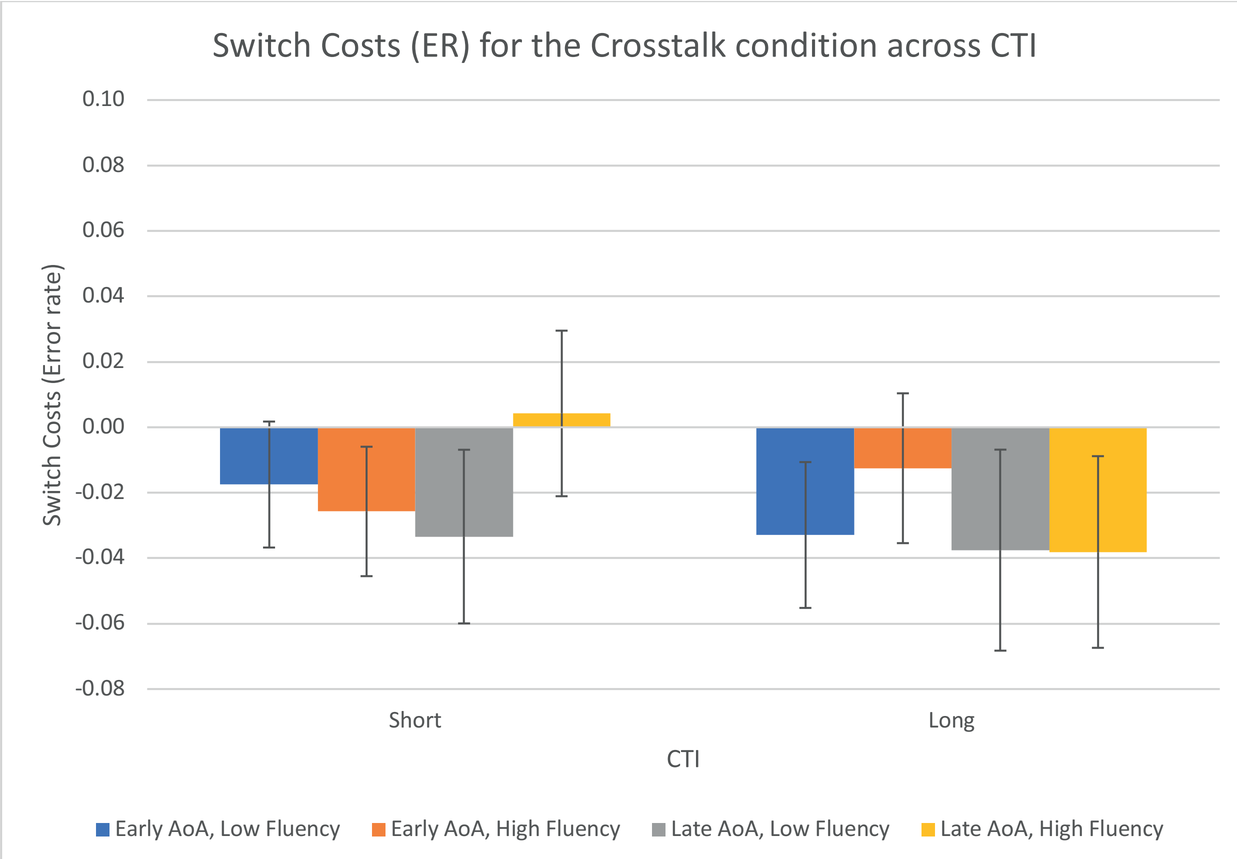

FIGURE 13. Switch costs for the crosstalk condition across both CTIs.

There was a significant 5-way interaction of Task, Crosstalk, CTI, Trial Type and fluency, $F(1, 54) = 4.20$, $MSE = 004$, $p = .045$, $\eta_p^2 = .072$, see Figure 14 and Figure 15. With the color task at the short CTI, the switch cost for the no-crosstalk condition was smallest for the low fluency (MD = .049) group, and largest for the high fluency (MD = .076) group. At the short CTI in the crosstalk condition there were no switch costs. In fact, both the high fluency and the low fluency groups performed better on switch than non-switch trials (MD = -0.018 and MD = -0.015 respectively). With the color task at the long CTI, the switch cost for the no-crosstalk condition was smallest for the low fluency (MD = .039) and largest for the high fluency (MD = .047) group. The switch cost at the long CTI in the crosstalk condition was only present for the high fluency (MD = .005) group, whereas the low fluency showed less errors on switch than nonswitch trials (MD = -0.022). With the shape task at the short CTI, the switch cost for the no-crosstalk condition was smallest for the high fluency (MD = .036) group, and largest for the low fluency (MD = .044) group. At the short CTI in the crosstalk condition there were no switch costs. In fact, both the low fluency and the high fluency groups showed less errors on switch than non-switch trials (MD = -0.036 and MD = -0.004 respectively). With the shape task at the long CTI, the switch cost for the no-crosstalk condition was smallest for the low fluency (MD = .047) and largest for the high fluency (MD = .051) group. At the long CTI in the crosstalk condition there were no switch costs. In fact, both the high fluency and the low fluency groups showed less errors on switch than non-switch trials (MD = -0.055 and MD = -0.048 respectively).

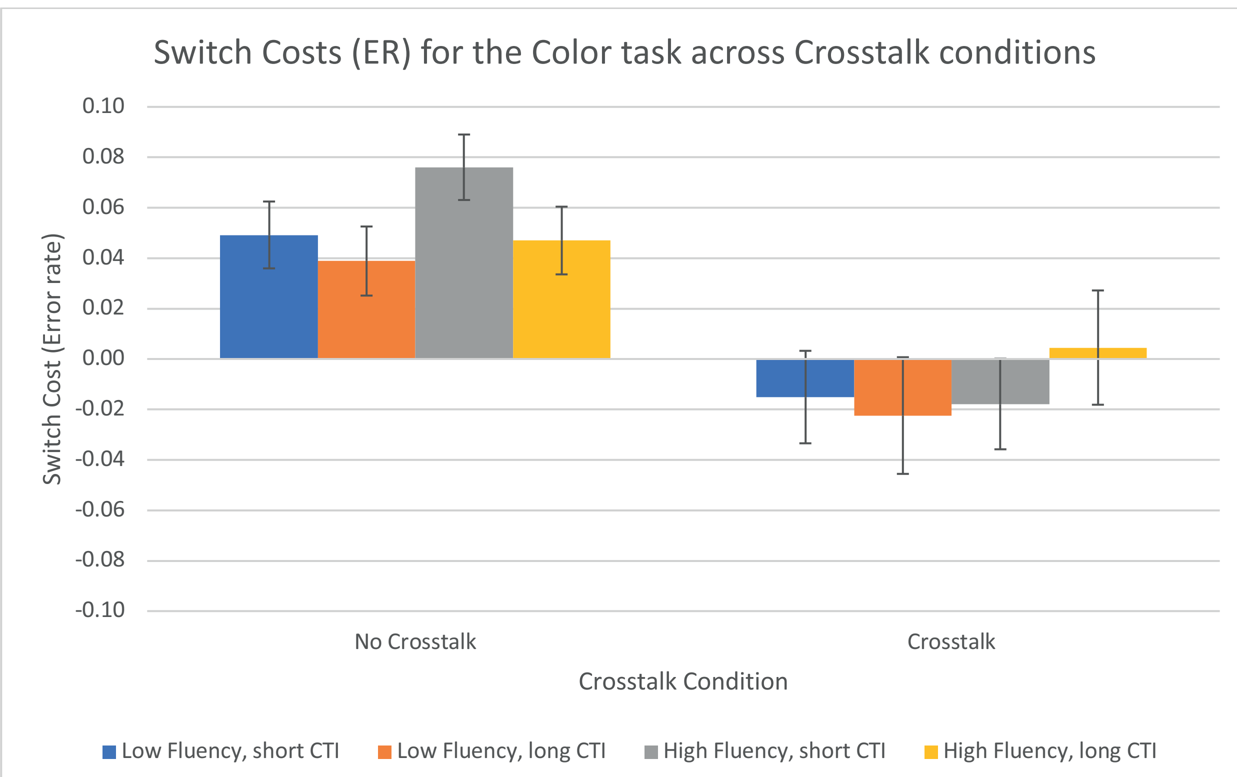

FIGURE 14. Switch costs for the color task across crosstalk condition and CTIs.

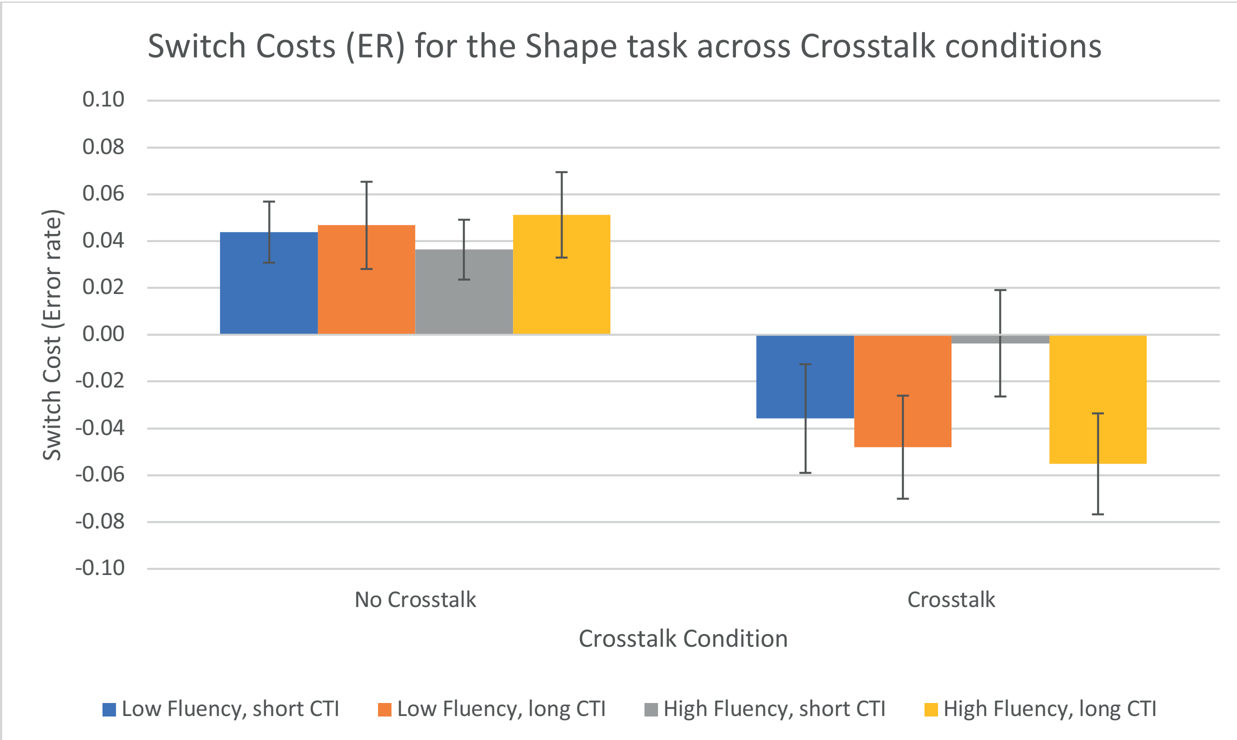

FIGURE 15. Switch costs for the shape task across crosstalk condition and CTIs.

3.3. Correlations

Pearson's correlation was computed to assess the relationships between switch costs and the participant's age or fluency for reaction time and error rate. Two participants were excluded from the correlations with age because they declined to answer the age question in the demographics survey.

For both RT, $r(55) = .04$, $p = .768$, and ER, $r(55) = -.21$, $p = .120$, age and switch costs were not significantly correlated. Similarly, fluency and switch cost were not significantly correlated for both RT, $r(57) = .22$, $p = .10$, and ER, $r(57) = .02$, $p = .895$.

An additional Pearson's correlation was computed to assess the relationship between AoA and fluency. Correlation showed that there was a significant negative correlation, $r(57) =$ -

.33, $p = .012$, meaning that participants that learned a language at a younger age (i.e., lower AoA) had higher fluency.

CHAPTER 4

DISCUSSION

The aim of this study was to discover what aspects of bilingualism may be involved in producing the bilingual advantage that has been shown in task-switching, where bilinguals show reduced switch costs compared to monolinguals (e.g., Prior & Gollan, 2011; Prior & MacWhinney, 2010; Wiseheart et al., 2016). Whereas prior studies have compared monolingual and bilingual participants (e.g., Barac & Bialystok, 2012; Costa et al., 2008; Wiseheart et al., 2016) or taken a single variable (AoA or fluency) to differentiate between a characteristic of bilinguals (e.g., Pelham & Abrams, 2014; Soveri et al., 2011; Tse and Altarriba, 2015), the present study examined whether fluency or AoA exerts a larger influence on executive control in task switching, and whether these two factors interact with each other.

To determine how AoA and fluency impacted task switch costs, several variables known to influence the size of the switch costs were also examined. The variables of CTI (preparation), crosstalk (stimulus interference), and block half (practice on task) were chosen to help understand *how* AoA and fluency affect task switching.

Given that prior research has shown evidence of a bilingual advantage that may differ between bilinguals, it was predicted that AoA and fluency would both have main effects, but it was also predicted that additional preparation could have lowered or removed this difference between groups (i.e., CTI would interact with AoA and fluency). The results did not show any main effects of AoA or fluency, in either the RT or ER data. CTI also did not enter into significant two-way interactions with AoA or fluency. Thus, none of the hypotheses were supported. In addition to the three hypotheses, the general research question of how does the combined effects of AoA and fluency influence the task-switching performance of bilinguals was also examined. The results showed that AoA and fluency did interact significantly with other variables, but no clear picture emerged to univocally make any conclusions about how these factors contribute to the bilingual advantage. This was due to other distinguishing factors that may have affected task switching performance observed by the bilingual participants in the current study, and the following sections discuss how the different factors may have affected task switching.

4.1. Task Switch Costs

The present study exclusively examined local switch costs (i.e., difference in both reaction time and error rate between switch and non-switch trials). The results showed significant switch costs of 63.08 ms and 0.012 errors, which replicates the previous findings (Rogers & Monsell, 1995). Because the current study did not include monolinguals, it is unknown whether these switch costs are smaller compared to that group. However, in comparison to Rogers and Monsell's study using similar CTIs, the switch cost obtained in the present study of 63 ms is smaller than the 205 ms switch cost obtained in their study.

Although there was no main effect of task (indicating that responding to color task takes a similar amount of time as responding to the shape task), the switch costs did differ between tasks. For reaction time, the switch cost was larger for the shape task than color task. The error rate data showed the opposite pattern, with ER showing a larger switch cost for the color task than the shape task. However, this latter effect was due to ER being lower for non-switch trials in the color task compared to the switch trials for the color task and both switch and non-switch trials for the shape task. Thus, the results indicate that differences in switch costs across tasks is a result of participants finding that it is easier to repeat the color task than shape task rather than a general speed-accuracy tradeoff.

4.2. Role of Interference

There was an interference effect of 119 ms and .027 errors. The main effects of crosstalk for the RT and ER analyses were expected because crosstalk produces more interference leading to a slowing of response times and increases in error rates (Rogers & Monsell, 1995). Crosstalk interacted significantly with trial type for both RT and ER. The switch costs were larger when there was no crosstalk than when crosstalk was present. In the crosstalk condition, participants needed to block out interference from the non-target stimulus dimension on both switch and non-switch trials leading to slower RT and high ER. In switch trials, participants had to also block out interference from the prior task, which made the response times highest for switch trials when crosstalk was present. Whereas when no crosstalk was present, RT was shortest and ER was lowest on non-switch trials compared to the other conditions. The reason for why the task switch cost is larger for the no crosstalk blocks than crosstalk blocks is that the reaction times were much shorter and ER much lower for the non-switch trials in the no crosstalk conditions. This benefit to performance is expected due to the reduced interference associated with these trials.

Both the RT and ER data showed significant 3-way interactions of Task, Crosstalk and CTI. For the color task, the interference effect (i.e., difference between crosstalk and no crosstalk trials) was larger at the long CTI than short CTI. However, for the shape task, the reverse pattern was obtained where the interference effect was larger at the short CTI than long CTI. However, this 3-way interaction was modified by significant higher-level interactions that are described later.

4.3. Role of Practice

Both the RT and ER data showed significant main effects for block half, where practice performing the task led to a 40 ms reduction in RT and .019 in errors during the second half of the block compared to the first half of the block. Thus, participants showed a consistent practice effect, similar to what has been found in prior studies (e.g., Cellier & Eyrolle, 1992). For RT, Block half entered into significant 2-way interactions with CTI and AoA, and 3-way interactions with AoA x fluency, and CTI x Crosstalk. Overall, participants showed a benefit of practice (i.e., reduced RT in the second half of the block compared to the first half) at the short CTI compared to the long CTI, but this pattern was mainly due to the effect of practice being smallest when crosstalk was present for the long CTI condition. Overall, the late AoA group showed a larger benefit of practice compared to the early AoA group. This interaction was driven by the early AoA-Low fluency group, which showed no change in RT across the two halves of the block, whereas all other groups showed a practice effect. It should be noted thought that the early AoA-Low fluency group showed the shortest RT of the four groups.

Finally, a 4-way interaction with Block half, Task, Crosstalk, and CTI was also obtained for RT. When no crosstalk was present, the practice effect for the color and shape tasks was the same at short CTI, but at the long CTI the practice effect was smaller for the color task and larger for the shape task. However, when crosstalk was present and the CTI was short, the practice effect was larger for the shape task than the color task. When crosstalk was present and the CTI was long, there was no practice effect: responses were only 4 ms faster on the second half than the first half when the task was color and in fact, responses were 30 ms slower when it was shape. The longer RTs on the second half of trials for the crosstalk conditions may be due to fatigue effects associated with the extra wait time with the long CTI.

4.4. Role of Preparation

This study used short and long CTI values similar to existing studies utilizing a cued task switching procedure (Meiran, 1996) but found unexpected results for CTI. It was expected that the longer CTI should provide participants with more time to reconfigure to the new task, which would typically lead to shorter reaction times. A significant main effect of CTI was obtained, but was the opposite pattern of what was hypothesized, where RT was 40 ms slower at the long CTI than short CTI. One possible reason for the pattern of this result is that the long CTI of 1350 ms was longer than the time that participants needed to reconfigure to the new task set. Thus, participants may have been prepared for the new task, but had to wait and this waiting could have led to attention wandering, which would have slowed down reaction time (see, e.g., inhibition of return, Klein, 2000).

Table 5 compares the RTs for the 600 ms and 1200 ms CTIs used by Rogers and Monsell (1995) with the 650 ms and 1350 ms CTIs used in the present study. In both studies, the response time is longer at the long CTI compared to the short CTI. However, for the present study, RTs for the non-switch trials were longer than those obtained by Rogers and Monsell, but RTs for the switch trials were shorter. It is not clear why these differences exist, but they are likely attributed to the differences in procedures (in-person vs. online), participants (monolinguals vs. bilinguals) and tasks (color/shape instead of letter/number) used in the two studies. Although the bilingual advantage can explain why the RTs for switch trials are lower in the present study than in Rogers and Monsell's study, it does not explain why the RTs are longer on non-switch trials. Thus, the group differences are likely due to a combination of methodological and participant differences.

TABLE 5. Short and Long Interval Comparison between Studies

Trial Type	Interval	Rogers & Monsell (ms)	This study (ms)
Switch trial	Short	913.5	810.81
	Long	924.4	853.46
Non-Switch trial	Short	708.2	750.68
	Long	720.5	787.42

There was a significant interaction of CTI, Task, and fluency. This interaction is mainly driven by the low fluency group showing the shortest reaction times for the color task at the short CTI. This is unexpected because the high fluency group would be expected to perform the best at the short CTI. The low fluency group may be faster in the short CTI condition because of other participant factors such as video game experience, which is known to reduce reaction time (Strobach et al., 2012). Video game experience was collected from the participants with demographic survey due to the known effect it can have on task switching (Strobach et al., 2012). As seen in Table 6, the low fluency group had a substantial amount more video game players (48.3% of participants in the low fluency group), with a higher average amount of time played than the participants in the high fluency group.

TABLE 6. Video Game Play Across Fluencies

Fluency	Participants that play video games (%)	Number of hours per week played (median category)
Low	48.28	5-6 hours
High	20.69	3-4 hours

For ER, there was a significant 3-way interaction between task, crosstalk, and CTI and a 4-way interaction of these variables with trial type. This 3-way interaction is due to the interference from crosstalk being smaller at the short than long CTI for the color task, but the reverse pattern was evident for the shape task. In the 4-way interaction when trial type is included, the switch cost was larger at the short than long CTI when no crosstalk was present for the color task, but when crosstalk was present, the error rate was lower on switch trials than non-switch trials, though the differences were similar at both CTIs. For the shape task, similar switch costs were obtained at both CTIs when no-crosstalk present. When crosstalk was present, the error rate was lower on switch trials than non-switch trials, with the difference being larger at the long than short CTI. The reason for the smaller switch costs in the crosstalk condition for the shape task at the long CTI is due to the higher error rates on the non-switch trials compared to the switch trials.

4.5. Role of AoA

The first hypothesis is that early AoA participants would perform better than late AoA participants because of their experience switching between languages (i.e., tasks). Although the main effect of AoA was not significant, the early AoA group did show numerically shorter reaction times. Because the early AoA participants already had shorter reaction times compared to the late AOA participants, there is not as much room for improvement with practice, as reflected in the Block Half x AoA interaction described earlier, where a practice effect was only evident for the late AoA group.

Participant variables in our sample that could have confounded the effects of AoA were video game experience and age. Based on the response to the post-experiment survey, it was determined that there was a large difference in age between AoA groups. The early AoA-low fluency group (mean age = 19 years) and early AoA-high fluency group (mean age = 19 years) were younger than the late AoA-low fluency group (mean age = 39 years) and late AoA-high fluency group (mean age = 42 years). Participant performance changes with age, with older adults showing longer overall RT and larger switch costs due to cognitive decline (Reimers & Maylor, 2005; Wasylyshyn et al., 2011). However there has also been other research that shows bilingualism may help in slowing cognitive decline (Bialystok et al., 2008). This latter point is supported by the correlation analysis, which showed that for this study there was not a significant correlation between age and switch costs for reaction time or error rate. AoA entered into three separate 5-way interactions with fluency which is discussed later.

4.6. Role of Fluency

Similar to AoA, the role of fluency was not clear as expected. There was no main effect of fluency. The low fluency group showed numerically lower RT than the high fluency group, which is the opposite of what was expected. As described above regarding the role of preparation, there was a 3-way interaction between task, CTI, and fluency. This interaction was mainly driven by the low fluency group showing the shortest reaction times for the color task at the short CTI, potentially due to other participant factors such as video game experience, which is known to reduce reaction time (Strobach et al., 2012).

For reaction time, the best performance was obtained for the Early AoA with low fluency group. Again, this group's superior performance may have also been due to video game experience. As seen in Table 7 (and the full frequency distribution in Figure 16), the Early AoA-Low fluency group had a substantial amount more video game players (57.9% of participants in the Early AoA-Low fluency group), with a higher average amount of time played.

TABLE 7. Video Game Play Across AoA and Fluency

AoA	Fluency	Participants that play video games (%)	Number of hours per week played (median category)
Early	Low	57.9%	7+ hours
	High	27.8%	3-4 hours
Late	Low	33.3%	1-2 hours
	High	0%	0

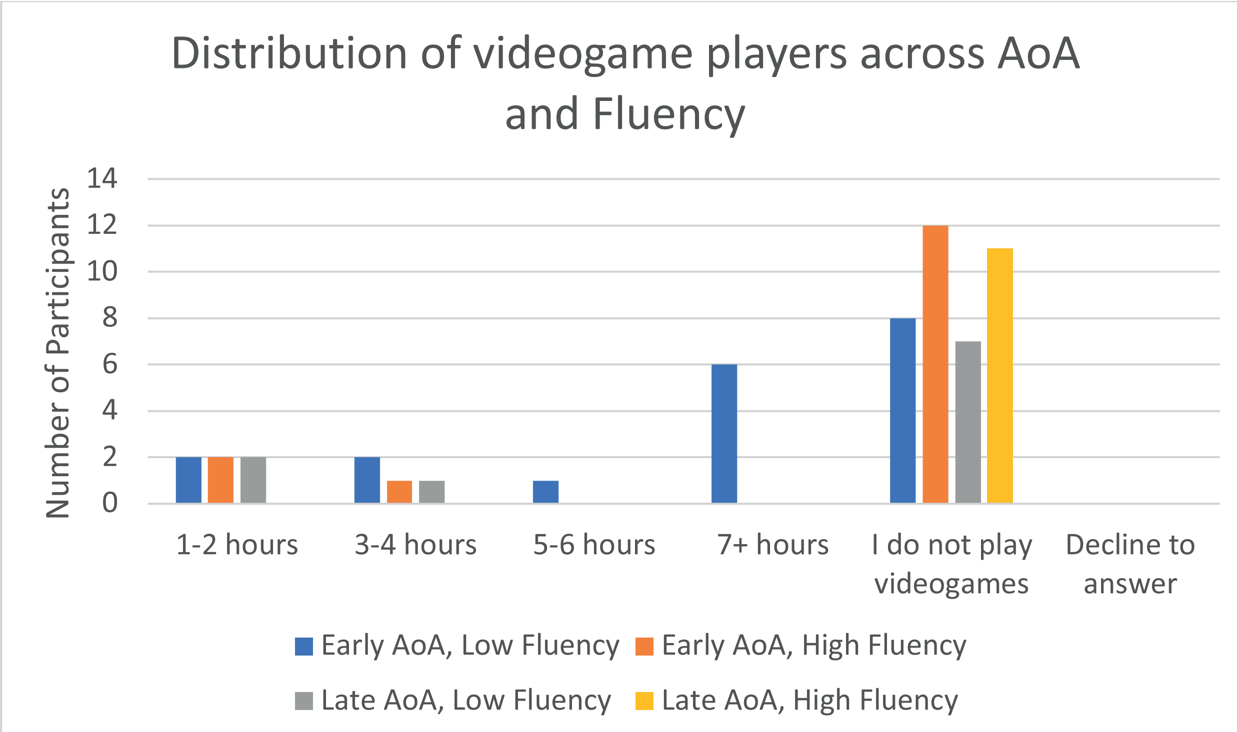

FIGURE 16. Video game frequency across AoA and fluency.

There were four 5-way interactions, all involving fluency, with three of them involving the combined effect AoA and fluency. The 5-way interaction involving Task, Crosstalk, CTI, Trial type, and fluency was obtained for ER. This interaction showed that in the color task, the low fluency group had lower error rates overall in all conditions. In addition, the low fluency group had lower switch costs than the high fluency group in all conditions except at short CTI in the crosstalk condition, where no switch cost was evident. Similarly, in the shape task, the low fluency group had lower error rates overall and had lower switch costs than the high fluency group at short CTI in the crosstalk condition, and at long CTI in no-crosstalk condition. At long CTI in the crosstalk condition both groups had lower error rates on switch than non-switch trials. Taken together, these findings do not support the notion that fluency is a critical factor in helping bilinguals reduce the error rate of switch costs or error rates in general. However, the reason that low fluency groups outperformed high fluency groups and had smaller switch costs may be due to the differences in the groups' exposure to video games, which could reduce their error rates on both switch and non-switch trials.

4.7. Joint Influence of AoA and Fluency

As mentioned earlier, there were three 5-way interactions involving both AoA and fluency. For RT, there was a 5-way interaction involving task, CTI, trial type, AoA, and fluency. For the color task, the switch cost was larger for participants with high fluency in most cases except for the late AoA-high fluency group at the short CTI. Although the late AoA group showed smaller switch costs at the short CTI for the high fluency group and at the long CTI for the low fluency group, this reduction in switch cost is likely due to the high RTs obtained in those conditions. In this interaction, performance was best for the early AoA-low fluency group. Similar to the color task, the switch cost was larger for participants with high fluency in most cases for the shape task, but the exception was for the late AoA group at the long CTI. The late AoA group showed larger switch costs for the low fluency group at the long CTI, but larger switch costs for the high fluency group at the short CTI. The early AoA group showed no difference in switch costs across CTI for the high fluency group but a larger switch cost at the short CTI for the low fluency group.

For RT, a 5-way interaction between Task, Crosstalk, Trial type, AoA, and fluency showed that for the color task, the results were consistent with all groups of participants showing no or smaller switch costs for RT when crosstalk was present than when it was not. When there was an absence of a switch cost, it was a result of the reaction time being elevated on non-switch trials rather than a reduction of reaction time on switch trials. The change in switch costs as a function of crosstalk was larger for the late AoA-high fluency group than for the other three groups. Again, performance was best for the early AoA-low fluency group. For the shape task, switch costs were present for both the no crosstalk and crosstalk conditions. Similar to the color task, the switch cost was smaller when crosstalk was present than when it was not for all four AoA/fluency groups. Again, the reduction of the switch costs was a result of the reaction time being elevated on non-switch trials rather than a reduction of reaction time on switch trials. In contrast to the color task, the early AoA-high fluency and late AoA-low fluency groups showed larger reductions than the other two groups.

Taken together, the two 5-way interactions for RT do not support the notion that early AoA and high fluency are the critical factor in helping bilinguals reduce the task switch costs. The best performance was observed for the early AoA-low fluency group. The early AOA-high fluency and late AOA-low fluency groups showed similar patterns of results, which tended to be different from late AoA-high fluency group. Although early acquisition of the second language seems to play a larger role than fluency, its effects are not uniform in the present study. The lack of a uniform effect with the early AoA group may be due to the differences in the group's exposure to video games, which could reduce their overall reaction times, leading to smaller group differences. The reason these differences may have not been so evident before is due to other studies primarily comparing bilinguals to monolinguals (for example, Prior & Gollan, 2011; Prior & MacWhinney, 2010) rather than different characteristics of bilinguals.

For ER, a 5-way interaction between Crosstalk, CTI, Trial type, AoA, and fluency was obtained. In general, at short and long CTI and across both crosstalk and no-crosstalk conditions, the late AoA-low fluency and early AoA-low fluency groups had lower switch costs. The exception was at long CTI when crosstalk was not present, where the early AoA-high fluency group had a similar switch cost, and at short CTI when crosstalk was present, where the early AoA-high fluency group had a similar difference in error rate between switch and non-switch trials. The late AoA-high fluency group had the second highest switch cost when crosstalk was not present at short CTI and the highest switch cost at long CTI. In the crosstalk condition the late AoA-high fluency group were the only group that showed a switch cost at short CTI, but then had the greatest difference between errors on switch and non-switch trials due to the highest error rate on non-switch trials of any condition. The low fluency groups overall had lower error rates than the early AoA-high fluency and late AoA-high fluency groups. The late AoA-high fluency group had the highest error rate out of any group.

When crosstalk was present, participants had more errors on non-switch than switch trials. This pattern was evident particularly for the early AoA-high fluency group at short CTI and the late AoA-high fluency group at long CTI where the groups had the highest error rates of any condition. This is due to the interference from crosstalk, which the participants were not anticipating on non-switch trials. Similar to the RT findings, the ER data do not support the univocal effects of fluency and AoA in helping bilinguals reduce the error rate of switch costs. The reason that low fluency groups outperformed high fluency groups and had lower switch costs may be due to the differences in the groups' exposure to video games, which could reduce their error rates on both switch and non-switch trials.

Because the 5-way interactions are complex, the following will summarize the group differences between the four AoA and fluency combinations for the main effects examined in the task-switching literature: switch costs, preparation effects, interference effects, and practice effects. For reaction time, the early AoA-low fluency group had the smallest switch costs (see Figure 17) and no practice effect (see Figure 18), the late AoA-low fluency group had the largest inverse preparation effect (see Figure 19) and the smallest interference effect (see Figure 20).

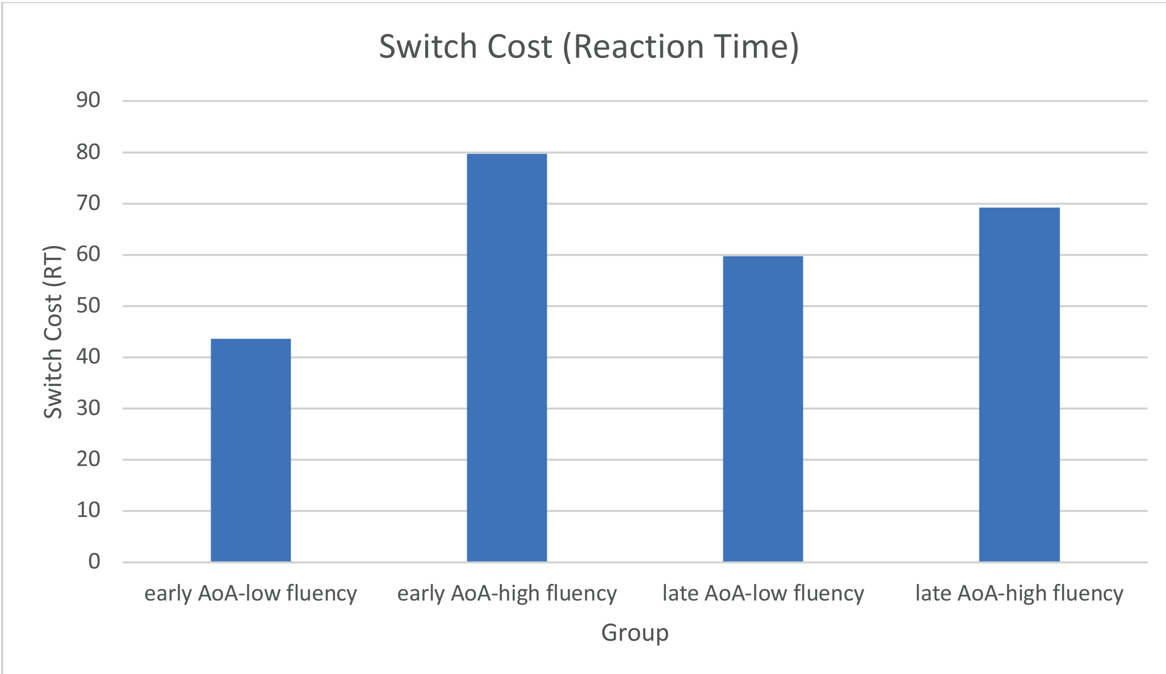

FIGURE 17. Switch costs (RT).

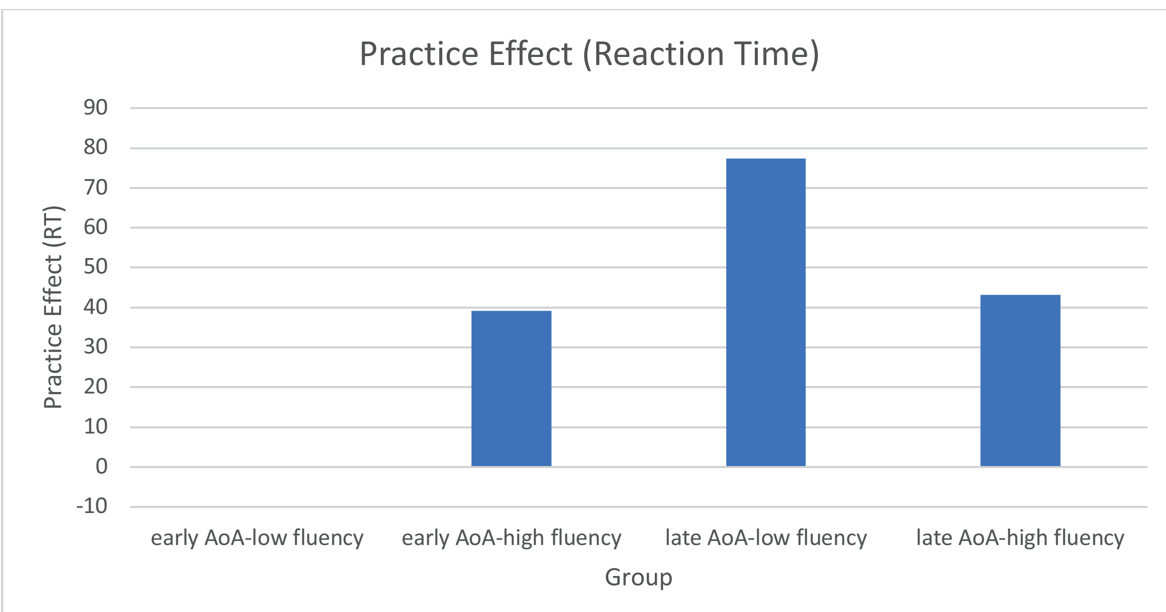

FIGURE 18. Practice effect (RT).

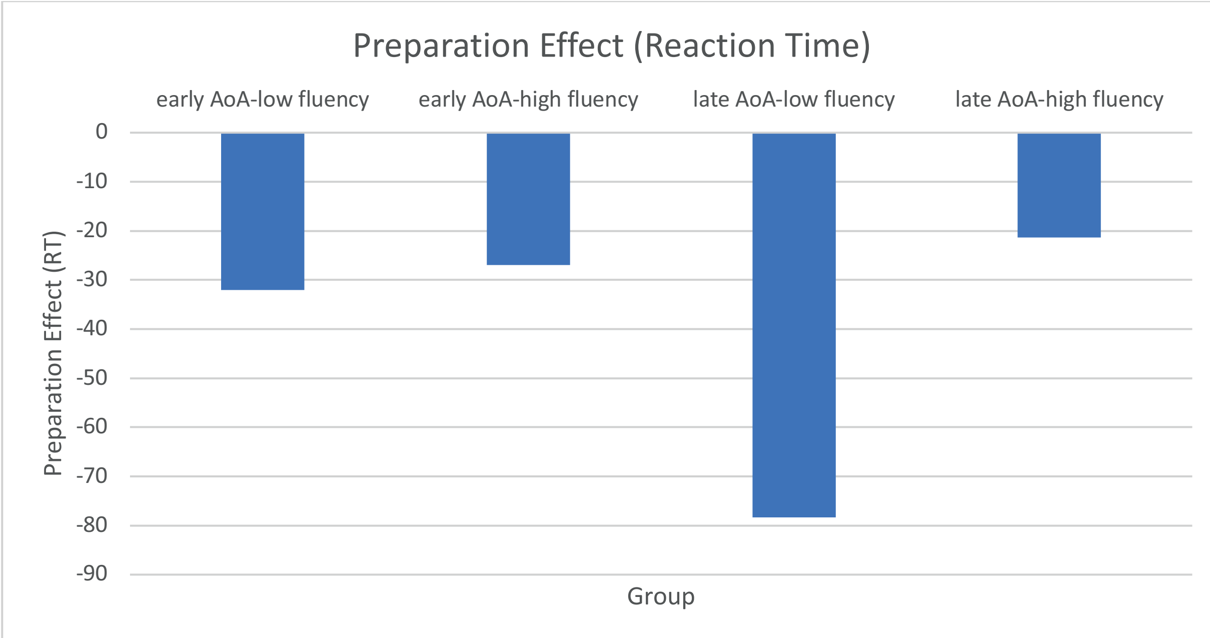

FIGURE 19. Preparation effect (RT).

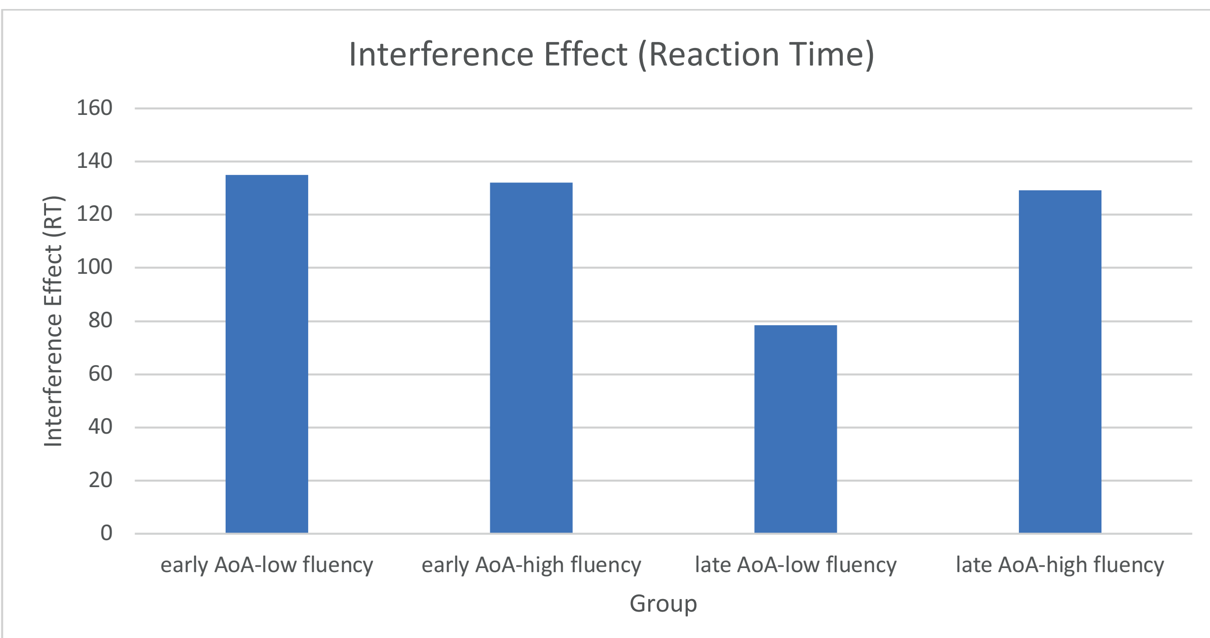

FIGURE 20. Interference effect (RT).

For error rate, the late AoA-low fluency group had the smallest switch costs, and the late AoA-high fluency group had the greatest (see Figure 21), the early AoA-high fluency group was the only group to see a preparation effect (see Figure 22), the late AoA-low fluency group had the smallest interference effect (see Figure 23), and the early AoA-low fluency group had smallest practice effect (see Figure 24).

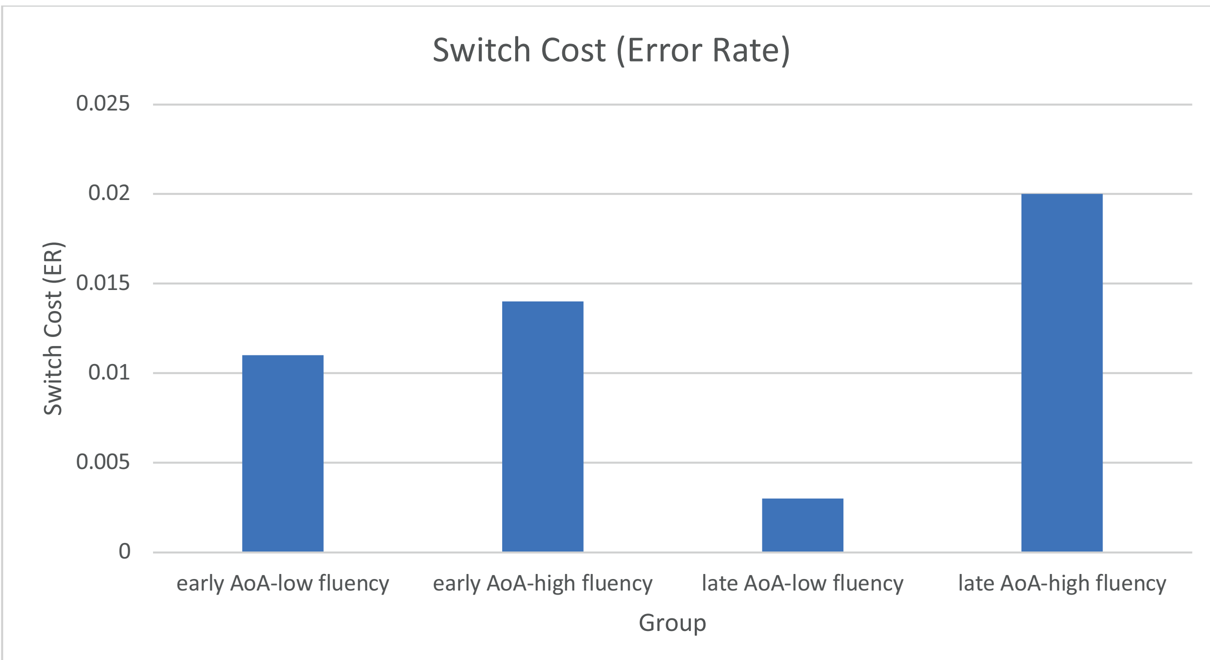

FIGURE 21. Switch costs (ER).

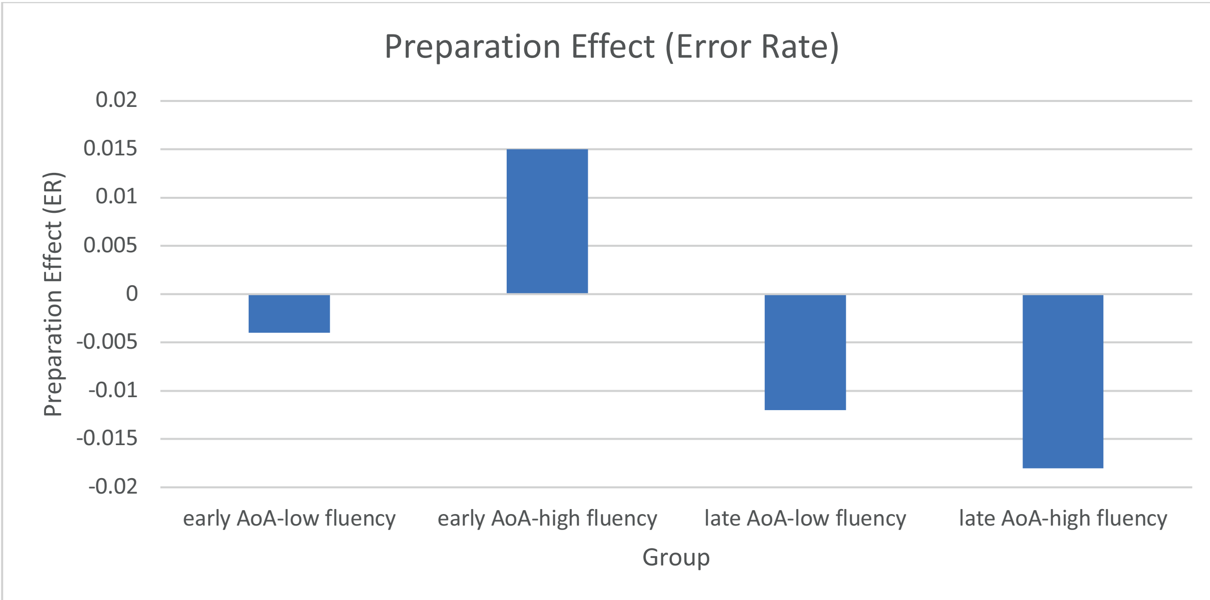

FIGURE 22. Preparation effect (ER).

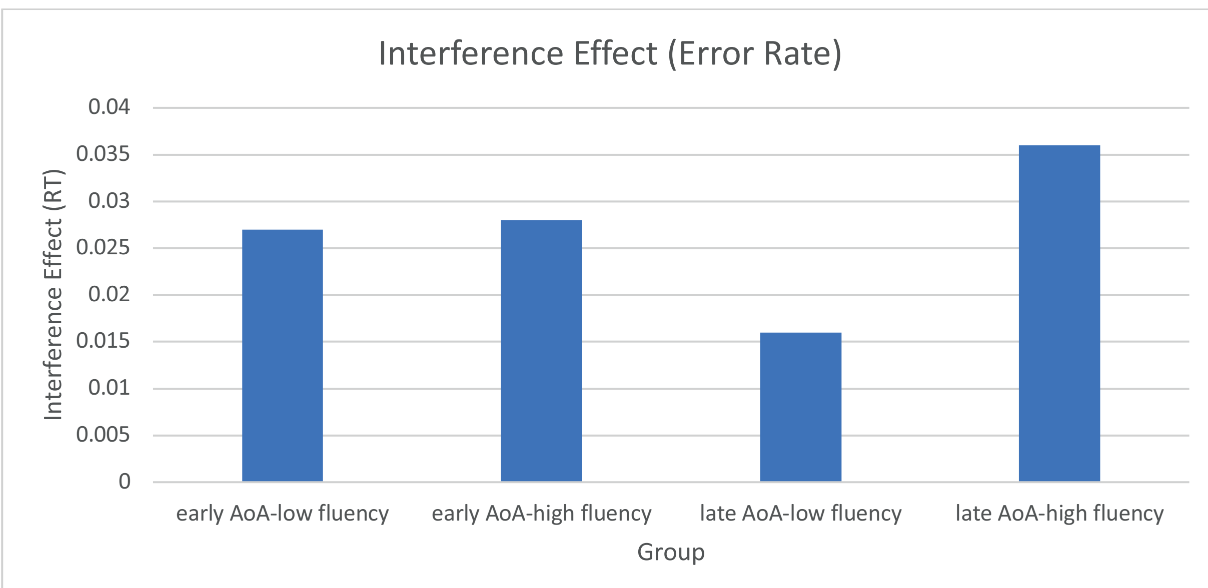

FIGURE 23. Interference effect (ER).

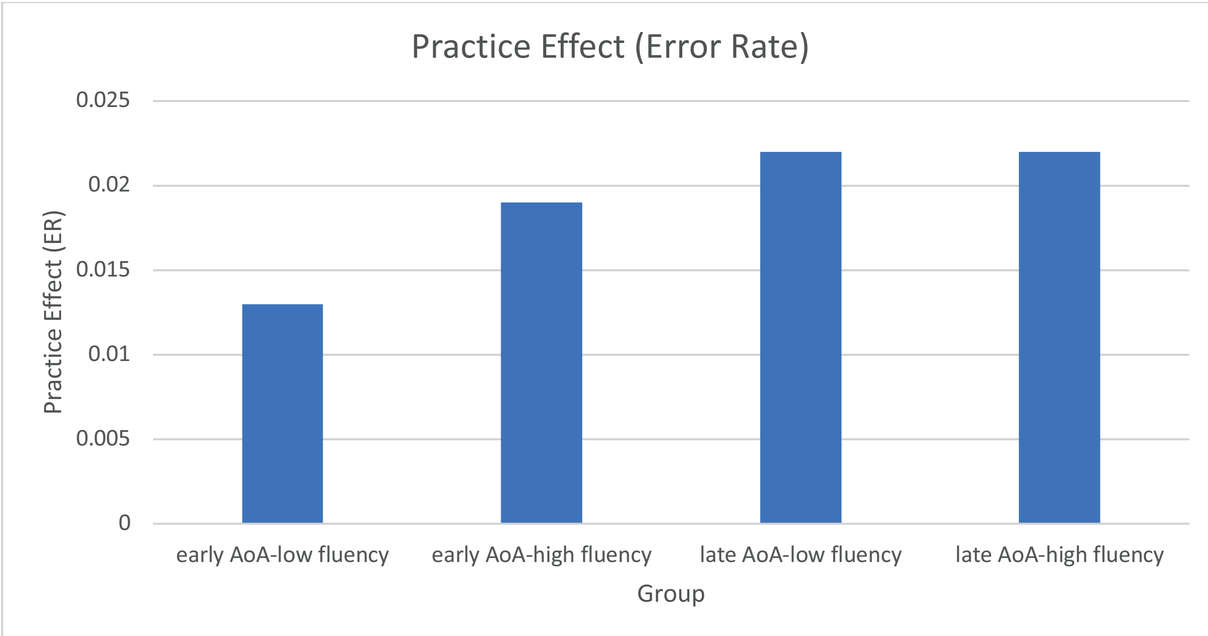

FIGURE 24. Practice effect (ER).

It may be the case that the different AoA-fluency combinations are responsible for the pattern of effects summarized above. However, as noted, there seems to be confounding demographic variables such as videogame experience. There is no obvious reason for why the early AoA-low fluency group included more video gamers in general, and more gamers who spend more than 4 hours per week playing videogames in particular. Perhaps playing videogames have led to this group having less social interaction, which may have in turn led to their low fluency. Of course, this is just mere speculation and other latent factors could have played a role.

CHAPTER 5

CONCLUSION

This study sought to determine the components of bilingualism that lead to the advantages of executive control that are known to reduce task switch costs. The results showed that AoA and self-described fluency were not the salient participant characteristics in the current sample to determine their link to the bilingual advantage. When considering both fluency and AoA, the early AoA- low fluency group showed the best performance, but this may be tied to another participant variable, that of video game experience.

5.1. Limitations

This study was performed during the COVID-19 pandemic and restrictions were in place that prevented in-person data collection with human participants. Therefore, this study had to be performed remotely through an online platform. There are multiple problems that can arise from remote testing. The first is that the environment cannot be controlled, and this is particularly important for task-switching studies, because distractions lead to longer reaction times and errors. Because the study was conducted online, the experimenter was not present to determine if the procedure was followed correctly. Other factors such as different computers, different screen sizes, and distance from the screen were not controlled for and could have impacted the participants' performance.

Another limitation was that the participants in different groups were mainly from different subject pools. Original recruitment was supposed to occur with Introductory Psychology Students, recruited through the SONA system at CSULB. However, after a month sign-up rates were low, specifically for participants in the late AoA group. At the end of the semester, additional recruitment was done through MTurk and use of snowball sampling (i.e., word-of-mouth recruitment). And this recruitment effort led to a small number of late AoA participants, but this meant that the participants in both groups differed in ways other than when they acquired a second language, such as level of education and age. Although age showed no significant correlation with either reaction time or error rate, there are other differences in participant variables that were confounded with AoA, with video game experience appearing to be a critical one.

Finally, a limitation around fluency was that it was self-described. Ideally fluency should be tested to confirm levels in different areas such as speaking and reading, though this may have been very challenging given the remote participation requirements, particularly when recruitment was already challenging. The distribution of fluency scores was examined to determine the threshold for a median split, but most participants had scores between 7 and 10. The 8.5 cutoff may not necessarily have produced groups that were much higher in fluency compared to the low fluency group. The small sample size prevented using smaller percentiles to group participants in terms of fluency.

5.2. Future Studies

The findings from this study resulted in more questions than answers. There was some evidence to support that AoA may be a stronger contributor to the bilingual advantage than fluency, but additional data is needed before any firm conclusions can be made. Future research should examine other factors that differentiate bilingual characteristics to determine what factors help produce the bilingual advantage. One such example would be to account for how frequently participants switch between languages rather than using their self-described fluency level, as this has also been shown to have an effect on task switch costs (Yow & Li, 2015).

Another direction of research would be to study whether the same effects are seen across bilinguals of different languages, as certain aspects of interference from different languages may lead to differences in executive control. Spanish-English bilinguals were selected for the present study because there is a large population of them in Southern California, but there are similarities between the two languages that do not exist in some other languages. For example, the letters are the same other than accents, and most character sounds are used across both languages, and though the sound may not refer to the same letter, it may make the languages easier to switch between.

Although task switching experiments commonly use local switch costs, there are other ways to calculate task switch costs that may show differing results. Yow and Li (2015) showed bilinguals have improvements to mixing costs rather than local switch costs. This study exclusively measured local switch costs and future studies could measure mixing costs along with local switch costs to reveal other insights. Finally, additional research is also warranted on varying long CTI intervals, to determine what CTI may be *too* long, eliminating the benefit of preparation.

5.3. Implications for Design

The results of the present study provide two implications for design. First, is that when designing systems and interfaces that require task switching, interference between tasks should be reduced to facilitate fast and accurate responding. However, if crosstalk is present, allow operators and end users time to practice with the system or interface to help them perform the tasks more efficiently with less errors. Second, if a system or interface uses cues to help operators or end users to prepare for up-coming tasks, ensure that the preparation interval is not too long. Use of long preparation or warning times may decrease the benefit of these cues. For example, reminders can help users prepare to switch between tasks, however, a reminder that occurs too early may not be attended to or cause users to minder wander or engage in other tasks while waiting.

APPENDICES

APPENDIX A

DEMOGRAPHIC INFORMATION SURVEY

Demographic information survey

1. **What is your age? _____**
2. **What is your gender?**
   a) Male
   b) Female
3. **What is your ethnicity?**
   a) Caucasian
   b) African American
   c) African
   d) Latino or Hispanic
   e) Asian
   f) Two or more ethnicities
   g) Middle eastern/Arabic
   h) Prefer not to say
   i) Other _____
4. **Do you play video games?**
   a) Yes
   b) No
5. **If Yes, how many hours *per week* have you played video games over the last 6 months?**
   a) 1-2 hours
   b) 3-4 hours
   c) 5-6 hours
   d) 7+ hours
   e) I do not play video games
6. **What device did you use to perform this study?**
   a) Desktop or personal computer/mac
   b) Laptop
   c) Tablet
   d) Mobile phone

APPENDIX B

LANGUAGE EXPERIENCE AND PROFICIENCY QUESTIONNAIRE (LEAP-Q)

Language Experience and Proficiency Questionnaire (LEAP-Q)

(1) Please list all languages you know in order of dominance

1.	2.	3.	4.	5.

(2) Please list all languages you know in order of acquisition (Your native language first):

1.	2.	3.	4.	5.

(3) Please list what percentage of time you are currently and on average exposed to each language. (Your percentages should add up to 100%):

List language here:				
List percentage here:				

(4) When choosing to read a text available in all your languages, in what percentage of cases would you choose to read it in each language? Assume that the original was written in another language, which is unknown to you. (Your percentages should add up to 100%):

List language here:				
List percentage here:				

(5) When choosing a language to speak with a person who is equally fluent in all your languages, what percentage of time would you speak each language? Please report percent of total time. (Your percentages should add up to 100%):

List language here:				
List percentage here:				

(6) How many years of formal education do you have (beyond high school)?

____

Please check your highest education level:

□	Less than high school	□	Some college	□	Masters
□	High school	□	College	□	PhD/MD/JD
□	Professional Training	□	Some graduate school	□	Other:

Language: ______

This is my (**native** **second** **third** **fourth** **fifth**) language.

(1) Age when you…

Began acquiring this language:	Became fluent in this language:	Began reading in this language:	Became fluent in reading this language:

(2) Please circle your level of proficiency along the following dimensions:

Speaking

0	1	2	3	4	5	6	7	8	9	10
None	Very low	Low	Fair	Slightly less than adequate	Adequate	Slightly more than adequate	Good	Very good	Excellent	Perfect

Reading

0	1	2	3	4	5	6	7	8	9	10
None	Very low	Low	Fair	Slightly less than adequate	Adequate	Slightly more than adequate	Good	Very good	Excellent	Perfect

Listening

0	1	2	3	4	5	6	7	8	9	10
None	Very low	Low	Fair	Slightly less than adequate	Adequate	Slightly more than adequate	Good	Very good	Excellent	Perfect

Writing

0	1	2	3	4	5	6	7	8	9	10
None	Very low	Low	Fair	Slightly less than adequate	Adequate	Slightly more than adequate	Good	Very good	Excellent	Perfect

(4) Please circle how much the following factors contributed to you learning this language:

Interacting with friends

0 1 2 3 4 5 6 7 8 9 10
Not a contributor Moderate contributor Most important contributor

Interacting with family

0 1 2 3 4 5 6 7 8 9 10
Not a contributor Moderate contributor Most important contributor

Reading

0 1 2 3 4 5 6 7 8 9 10
Not a contributor Moderate contributor Most important contributor

Language tapes/self-instruction

0 1 2 3 4 5 6 7 8 9 10
Not a contributor Moderate contributor Most important contributor

Watching TV

0 1 2 3 4 5 6 7 8 9 10
Not a contributor Moderate contributor Most important contributor

Listening to the radio

0	1	2	3	4	5	6	7	8	9	10
Not a contributor					Moderate contributor			Most important contributor		

(5) Please circle to what extent you are currently exposed to this language in the following contexts:

Interacting with friends

0	1	2	3	4	5	6	7	8	9	10
Never	Almost never				Half the time					Always

Interacting with family

0	1	2	3	4	5	6	7	8	9	10
Never	Almost never				Half the time					Always

Watching TV

0	1	2	3	4	5	6	7	8	9	10
Never	Almost never				Half the time					Always

Listening to radio/music

0	1	2	3	4	5	6	7	8	9	10
Never	Almost never				Half the time					Always

Reading

0	1	2	3	4	5	6	7	8	9	10
Never	Almost never				Half the time					Always

Language-lab/self-instruction

0	1	2	3	4	5	6	7	8	9	10
Never	Almost never				Half the time					Always

(6) In your perception, how much of a foreign accent do you have in this language?

0	1	2	3	4	5	6	7	8	9	10
None		Very light			Moderate			Very heavy		Pervasive

(7) Please circle how frequently others identify you as a non-native speaker based on your accent in this language:

0	1	2	3	4	5	6	7	8	9	10
Never	Almost never				Half the time					Always

APPENDIX C

TABLE 1. DEMOGRAPHICS

TABLE 1. Demographics

Group	N	Age (mean)	Fluency score (mean)	English-dominant (%)	Spanish-dominant (%)	Education Level (mode)
Early AoA Low Fluency	19	19	7.17	94.7%	5.3%	Some College
Early AoA High Fluency	18	19	9.47	66.7%	33.3%	Some College
Late AoA Low Fluency	10	39	5.50	40%	60%	High School
Late AoA High Fluency	11	42	8.61	9%	91%	Some College

APPENDIX D

TABLE 2. PARTICIPANT SUBJECT POOL

TABLE 2. Participant Subject Pools

Group	SONA (PSY 100) (%)	MTurk (%)	Snowball (%)
Early AoA Low Fluency	100%	0%	0%
Early AoA High Fluency	100%	0%	0%
Late AoA Low Fluency	10%	0%	90%
Late AoA High Fluency	18%	9%	73%

APPENDIX E

TABLE 3. MEAN REACTION TIMES

TABLE 3. Mean Reaction Times

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
early	Low	Color	No Crosstalk	Short	1	Nonswitch	624.95	198.90
						Switch	680.53	235.88
					2	Nonswitch	605.37	154.49
						Switch	668.95	180.04
				Long	1	Nonswitch	677.21	154.45
						Switch	749.89	200.28
					2	Nonswitch	647.79	151.77
						Switch	701.26	200.37
			Crosstalk	Short	1	Nonswitch	777.21	230.77
						Switch	753.89	254.28
					2	Nonswitch	795.53	269.00
						Switch	769.21	248.02
				Long	1	Nonswitch	762.95	253.82
						Switch	806.79	281.00
					2	Nonswitch	841.53	246.61
						Switch	859.05	226.53
		Shape	No Crosstalk	Short	1	Nonswitch	591.58	184.18
						Switch	696.00	217.37
					2	Nonswitch	579.47	152.27
						Switch	671.95	174.45
				Long	1	Nonswitch	675.95	201.90
						Switch	737.63	238.62
					2	Nonswitch	628.84	154.19
						Switch	701.79	184.68

TABLE 3. Continued

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
			Crosstalk	Short	1	Nonswitch	795.89	255.80
						Switch	862.21	302.23
					2	Nonswitch	806.89	228.64
						Switch	783.84	232.43
				Long	1	Nonswitch	760.58	257.27
						Switch	765.89	247.58
					2	Nonswitch	798.89	233.23
						Switch	859.63	267.37
	High	Color	No Crosstalk	Short	1	Nonswitch	706.94	198.90
						Switch	824.44	235.88
					2	Nonswitch	634.67	154.49
						Switch	735.28	180.04
				Long	1	Nonswitch	715.78	154.45
						Switch	782.33	200.28
					2	Nonswitch	643.50	151.77
						Switch	762.06	200.37
			Crosstalk	Short	1	Nonswitch	809.06	230.77
						Switch	920.06	254.28
					2	Nonswitch	796.22	269.00
						Switch	835.39	248.02
				Long	1	Nonswitch	862.22	253.82
						Switch	859.50	281.00
					2	Nonswitch	863.44	246.61
						Switch	899.22	226.53

TABLE 3. Continued

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
		Shape	No Crosstalk	Short	1	Nonswitch	682.44	184.18
						Switch	819.39	217.37
					2	Nonswitch	604.67	152.27
						Switch	725.56	174.45
				Long	1	Nonswitch	747.78	201.90
						Switch	877.22	238.62
					2	Nonswitch	660.22	154.19
						Switch	794.44	184.68
			Crosstalk	Short	1	Nonswitch	861.72	255.80
						Switch	917.83	302.23
					2	Nonswitch	827.67	228.64
						Switch	856.11	232.43
				Long	1	Nonswitch	832.28	257.27
						Switch	868.22	247.58
					2	Nonswitch	887.00	233.23
						Switch	934.44	267.37
late	Low	Color	No Crosstalk	Short	1	Nonswitch	729.30	198.90
						Switch	801.70	235.88
					2	Nonswitch	669.50	154.49
						Switch	759.10	180.04
				Long	1	Nonswitch	832.30	154.45
						Switch	866.20	200.28
					2	Nonswitch	768.50	151.77

TABLE 3. Continued

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
						Switch	805.50	200.37
			Crosstalk	Short	1	Nonswitch	814.20	230.77
						Switch	839.20	254.28
					2	Nonswitch	789.80	269.00
						Switch	755.50	248.02
				Long	1	Nonswitch	935.20	253.82
						Switch	975.50	281.00
					2	Nonswitch	905.60	246.61
						Switch	886.00	226.53
		Shape	No Crosstalk	Short	1	Nonswitch	732.60	184.18
						Switch	869.60	217.37
					2	Nonswitch	680.20	152.27
						Switch	790.50	174.45
				Long	1	Nonswitch	832.40	201.90
						Switch	1013.60	238.62
					2	Nonswitch	701.50	154.19
						Switch	829.00	184.68
			Crosstalk	Short	1	Nonswitch	898.30	255.80
						Switch	932.80	302.23
					2	Nonswitch	806.60	228.64
						Switch	814.00	232.43
				Long	1	Nonswitch	898.80	257.27
						Switch	956.90	247.58
					2	Nonswitch	836.90	233.23

TABLE 3. Continued

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
						Switch	893.00	267.37
	High	Color	No Crosstalk	Short	1	Nonswitch	717.64	198.90
						Switch	878.00	235.88
					2	Nonswitch	690.09	154.49
						Switch	764.18	180.04
				Long	1	Nonswitch	684.82	154.45
						Switch	834.55	200.28
					2	Nonswitch	704.36	151.77
						Switch	863.64	200.37
			Crosstalk	Short	1	Nonswitch	962.73	230.77
						Switch	867.91	254.28
					2	Nonswitch	852.45	269.00
						Switch	785.00	248.02
				Long	1	Nonswitch	920.09	253.82
						Switch	943.36	281.00
					2	Nonswitch	876.36	246.61
						Switch	900.64	226.53
		Shape	No Crosstalk	Short	1	Nonswitch	712.00	184.18
						Switch	885.91	217.37
					2	Nonswitch	687.45	152.27
						Switch	776.73	174.45
				Long	1	Nonswitch	779.64	201.90
						Switch	851.45	238.62
					2	Nonswitch	731.45	154.19

TABLE 3. Continued

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
						Switch	839.91	184.68
			Crosstalk	Short	1	Nonswitch	945.45	255.80
						Switch	1014.64	302.23
					2	Nonswitch	833.09	228.64
						Switch	890.36	232.43
				Long	1	Nonswitch	849.91	257.27
						Switch	932.27	247.58
					2	Nonswitch	933.55	233.23
						Switch	959.73	267.37

APPENDIX F

TABLE 4. MEAN ERROR RATES

TABLE 4. Mean Error Rates

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
early	Low	Color	No Crosstalk	Short	1	Nonswitch	< .001	0.011
						Switch	0.053	0.088
					2	Nonswitch	0.004	0.016
						Switch	0.048	0.086
				Long	1	Nonswitch	< .001	0.047
						Switch	0.053	0.102
					2	Nonswitch	0.004	0.035
						Switch	0.049	0.069
			Crosstalk	Short	1	Nonswitch	0.044	0.107
						Switch	0.061	0.094
					2	Nonswitch	0.039	0.078
						Switch	0.053	0.059
				Long	1	Nonswitch	0.071	0.093
						Switch	0.053	0.101
					2	Nonswitch	0.066	0.113
						Switch	0.044	0.081
		Shape	No Crosstalk	Short	1	Nonswitch	< .001	0.043
						Switch	0.048	0.082
					2	Nonswitch	0.000	0.028
						Switch	0.026	0.061
				Long	1	Nonswitch	0.004	0.061
						Switch	0.093	0.101
					2	Nonswitch	0.009	0.049
						Switch	0.031	0.093
			Crosstalk	Short	1	Nonswitch	0.114	0.133
						Switch	0.049	0.113
					2	Nonswitch	0.053	0.081
						Switch	0.017	0.070
				Long	1	Nonswitch	0.066	0.118
						Switch	0.035	0.083
					2	Nonswitch	0.075	0.114
						Switch	0.013	0.037
	High	Color	No Crosstalk	Short	1	Nonswitch	0.005	0.011
						Switch	0.093	0.088

TABLE 4. Continued

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
					2	Nonswitch	0.005	0.016
						Switch	0.083	0.086
				Long	1	Nonswitch	0.028	0.047
						Switch	0.065	0.102
					2	Nonswitch	0.014	0.035
						Switch	0.028	0.069
			Crosstalk	Short	1	Nonswitch	0.098	0.107
						Switch	0.083	0.094
					2	Nonswitch	0.075	0.078
						Switch	0.033	0.059
				Long	1	Nonswitch	0.051	0.093
						Switch	0.075	0.101
					2	Nonswitch	0.051	0.113
						Switch	0.061	0.081
		Shape	No Crosstalk	Short	1	Nonswitch	0.019	0.043
						Switch	0.060	0.082
					2	Nonswitch	0.014	0.028
						Switch	0.056	0.061
				Long	1	Nonswitch	0.018	0.061
						Switch	0.051	0.101
					2	Nonswitch	0.009	0.049
						Switch	0.052	0.093
			Crosstalk	Short	1	Nonswitch	0.116	0.133
						Switch	0.088	0.113
					2	Nonswitch	0.070	0.081
						Switch	0.051	0.070
				Long	1	Nonswitch	0.088	0.118
						Switch	0.042	0.083
					2	Nonswitch	0.051	0.114
						Switch	0.014	0.037
late	Low	Color	No Crosstalk	Short	1	Nonswitch	< .001	0.011
						Switch	0.059	0.088
					2	Nonswitch	< .001	0.016
						Switch	0.042	0.086
				Long	1	Nonswitch	0.008	0.047

TABLE 4. Continued

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
						Switch	0.050	0.102
					2	Nonswitch	< .001	0.035
						Switch	0.017	0.069
			Crosstalk	Short	1	Nonswitch	0.066	0.107
						Switch	0.017	0.094
					2	Nonswitch	0.059	0.078
						Switch	0.017	0.059
				Long	1	Nonswitch	0.067	0.093
						Switch	0.041	0.101
					2	Nonswitch	0.058	0.113
						Switch	0.033	0.081
		Shape	No Crosstalk	Short	1	Nonswitch	0.025	0.043
						Switch	0.075	0.082
					2	Nonswitch	0.000	0.028
						Switch	0.051	0.061
				Long	1	Nonswitch	0.059	0.061
						Switch	0.109	0.101
					2	Nonswitch	0.033	0.049
						Switch	0.059	0.093
			Crosstalk	Short	1	Nonswitch	0.076	0.133
						Switch	0.059	0.113
					2	Nonswitch	0.050	0.081
						Switch	0.025	0.070
				Long	1	Nonswitch	0.117	0.118
						Switch	0.067	0.083
					2	Nonswitch	0.075	0.114
						Switch	0.025	0.037
	High	Color	No Crosstalk	Short	1	Nonswitch	< .001	0.011
						Switch	0.076	0.088
					2	Nonswitch	< .001	0.016
						Switch	0.061	0.086
				Long	1	Nonswitch	0.008	0.047
						Switch	0.098	0.102
					2	Nonswitch	0.015	0.035
						Switch	0.061	0.069

TABLE 4. Continued

AoA	Fluency	Task	Crosstalk	CTI	Block half	Trial type	*M*	*SD*
			Crosstalk	Short	1	Nonswitch	0.068	0.107
						Switch	0.069	0.094
					2	Nonswitch	0.038	0.078
						Switch	0.023	0.059
				Long	1	Nonswitch	0.107	0.093
						Switch	0.107	0.101
					2	Nonswitch	0.076	0.113
						Switch	0.061	0.081
		Shape	No Crosstalk	Short	1	Nonswitch	0.008	0.043
						Switch	0.062	0.082
					2	Nonswitch	0.015	0.028
						Switch	0.023	0.061
				Long	1	Nonswitch	0.023	0.061
						Switch	0.061	0.101
					2	Nonswitch	0.008	0.049
						Switch	0.099	0.093
			Crosstalk	Short	1	Nonswitch	0.106	0.133
						Switch	0.091	0.113
					2	Nonswitch	0.038	0.081
						Switch	0.084	0.070
				Long	1	Nonswitch	0.121	0.118
						Switch	0.084	0.083
					2	Nonswitch	0.115	0.114
						Switch	0.015	0.037

APPENDIX G

TABLE 8. VIDEO GAME USAGE

TABLE 8. Video Game Usage

Group	Play video games (%)	Videogame hours per week (median category)
Early AoA Low Fluency	57.9%	7+ hours
Early AoA High Fluency	27.8%	3-4 hours
Late AoA Low Fluency	30.0%	1-2 hours
Late AoA High Fluency	0.0%	N/A

REFERENCES

REFERENCES

Alzahabi, R., & Becker, M. W. (2013). The association between media multitasking, task-switching, and dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(5), 1485-1495. https://doi.org/10.1037/a0031208

Barac, R., & Bialystok, E. (2012). Bilingual effects on cognitive and linguistic development: Role of language, cultural background, and education. *Child Development*, *83*(2), 413-422. https://doi.org/10.1111/j.1467-8624.2011.01707.x

Belleville, S., Bherer, L., Lepage, É., Chertkow, H., & Gauthier, S. (2008). Task switching capacities in persons with Alzheimer's disease and mild cognitive impairment. *Neuropsychologia*, *46*(8), 2225-2233. https://doi.org/10.1016/j.neuropsychologia.2008.02.012

Bialystok, E. (2010). Bilingualism. *Wiley Interdisciplinary Reviews: Cognitive Science*, *1*(4), 559-572. https://doi.org/10.1002/wcs.43

Bialystok, E. (2011). Reshaping the mind: The benefits of bilingualism. *Canadian Journal of Experimental Psychology*, *65*(4), 229-235. https://doi.org/10.1037/a0025406

Bialystok, E., & Barac, R. (2012). Emerging bilingualism: Dissociating advantages for metalinguistic awareness and executive control. *Cognition*, *122*(1), 67-73. https://doi.org/10.1016/j.cognition.2011.08.003

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(4), 859-873. https://doi.org/10.1037/0278-7393.34.4.859

Bialystok, E., Peets, K. F., & Moreno, S. (2014). Producing bilinguals through immersion education: Development of metalinguistic awareness. *Applied Psycholinguistics*, *35*(1), 177-191. https://doi.org/10.1017/S0142716412000288

Blanco-Elorrieta, E., & Pylkkänen, L. (2018). Ecological validity in bilingualism research and the bilingual advantage. *Trends in Cognitive Sciences*, *22*(12), 1117-1126. https://doi.org/10.1016/j.tics.2018.10.001

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica*, *129*(3), 387-398. https://doi.org/10.1016/j.actpsy.2008.09.005

Cellier, J.-M., & Eyrolle, H. (1992). Interference between switched tasks. *Ergonomics*, *35*(1), 25-36. https://doi.org/10.1080/00140139208967795

Chan, R. C., Lai, M. K., & Robertson, I. H. (2006). Latent structure of the test of everyday attention in a non-clinical Chinese sample. *Archives of Clinical Neuropsychology*, *21*(5), 477-485. https://doi.org/10.1016/j.acn.2006.06.007

Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition*, *106*(1), 59-86. https://doi.org/10.1016/j.cognition.2006.12.013

Costa, R. E., & Friedrich, F. J. (2012). Inhibition, interference, and conflict in task switching. *Psychonomic Bulletin & Review*, *19*(6), 1193-1201. https://doi.org/10.3758/s13423-012-0311-1

Cragg, L., & Nation, K. (2009). Shifting development in mid-childhood: The influence of between-task interference. *Developmental Psychology*, *45*(5), 1465-1479. https://doi.org/10.1037/a0015360

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, *44*(11), 2037-2078. https://doi.org/10.1016/j.neuropsychologia.2006.02.006

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*(1), 143-149. https://doi.org/10.3758/BF03203267

Hartanto, A., Toh, W. X., & Yang, H. (2016). Age matters: The effect of onset age of video game play on task-switching abilities. *Attention, Perception, & Psychophysics*, *78*(4), 1125-1136. https://doi.org/10.3758/s13414-016-1068-9

Huff, M. J., Balota, D. A., Minear, M., Aschenbrenner, A. J., & Duchek, J. M. (2015). Dissociative global and local task-switching costs across younger adults, middle-aged adults, older adults, and very mild Alzheimer's disease individuals. *Psychology and Aging*, *30*(4), 727-739. https://doi.org/10.1037/pag0000057

Jersild, A. T. (1927). Mental set and shift. *Archives of Psychology*, *89*, 1-81.

Kaushanskaya, M., Blumenfeld, H. K., & Marian, V. (2020). The Language Experience and Proficiency Questionnaire (LEAP-Q): Ten years later. *Bilingualism: Language and Cognition*, *23*(5), 945-950. https://doi.org/10.1017/S1366728919000038

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences*, *4*(4), 138-147. https://doi.org/10.1016/S1364-6613(00)01452-2

Koch, I., Gade, M., & Philipp, A. M. (2004). Inhibition of response mode in task switching. *Experimental Psychology*, *51*(1), 52-58. https://doi.org/10.1027/1618-3169.51.1.52

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging*, *15*(1), 126-147. https://doi.org/10.1037/0882-7974.15.1.126

Marian, V., Blumenfeld, H. K., & Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language, and Hearing Research*, *50*(4), 940-967. https://doi.org/10.1044/1092-4388(2007/067)

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*(6), 1423-1442. https://doi.org/10.1037/0278-7393.22.6.1423

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, *7*(3), 134-140. https://doi.org /10.1016/S1364-6613(03)00028-7

Moreno, S., Bialystok, E., Wodniecka, Z., & Alain, C. (2010). Conflict resolution in sentence processing by bilinguals. *Journal of Neurolinguistics*, *23*(6), 564-579. https://doi.org/10 .1016/j.jneuroling.2010.05.002

Ophir, E., Nass, C., Wagner, A. D., & Posner, M. I. (2009). Cognitive control in media multitaskers. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(37), 15583-15587. https://doi.org/10.1073/pnas.0903620106

Pelham, S. D., & Abrams, L. (2014). Cognitive advantages and disadvantages in early and late bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(2), 313-325. https://doi.org/10.1037/a0035224

Prior, A., & Gollan, T. H. (2011). Good language-switchers are good task-switchers: Evidence from Spanish-English and Mandarin-English bilinguals. *Journal of the International Neuropsychological Society*, *17*(4), 682-691. https://doi.org/10.1017 /S1355617711000 580

Prior, A., & MacWhinney, B. (2010). A bilingual advantage in task switching. *Bilingualism: Language and Cognition*, *13*(2), 253-262. https://doi.org/10.1017/S1366728909990526

Reimers, S., & Maylor, E. A. (2005). Task switching across the life span: Effects of age on general and specific switch costs. *Developmental Psychology*, *41*(4), 661-671. https://doi .org/10.1037/0012-1649.41.4.661

Robertson, I. H., Ward, T., & Ridgeway, V. (1994). *The Test of Everyday Attention (TEA).* Thames Valley Test Company.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictible switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*(2), 207-231. https://doi.org/10 .1037/0096-3445.124.2.207

Simon, J. R., & Rudell, A. P. (1967). Auditory SR compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology*, *51*(3), 300-304. https://doi.org/10.1037/h0020586

Soveri, A., Rodriguez-Fornells, A., & Laine, M. (2011). Is there a relationship between language switching and executive functions in bilingualism? Introducing a within group analysis approach. *Frontiers in Psychology*, *2*(183), 1-8. https://doi.org/10.3389/fpsyg.2011.00183

Spector, A., & Biederman, I. (1976). Mental set and mental shift revisited. *The American Journal of Psychology*, *89*(4), 669-679. https://doi.org/10.2307/1421465

Stoet, G. (2010). PsyToolkit: A software package for programming psychological experiments using Linux. *Behavior Research Methods*, *42*(4), 1096-1104. https://doi.org/10.3758/brm.42.4.1096

Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. *Teaching of Psychology*, *44*(1), 24-31. https://doi.org/10.1177/0098628316677643

Strobach, T., Frensch, P. A., & Schubert, T. (2012). Video game practice optimizes executive control skills in dual-task and task switching situations. *Acta Psychologica*, *140*(1), 13-24. https://doi.org/10.1016/j.actpsy.2012.02.001

Timmer, K., Calabria, M., & Costa, A. (2019). Non-linguistic effects of language switching training. *Cognition*, *182*, 14-24. https://doi.org/10.1016/j.cognition.2018.09.001

Tse, C.-S., & Altarriba, J. (2015). Local and global task switching costs in bilinguals who vary in second language proficiency. *The American Journal of Psychology*, *128*(1), 89-106. https://doi.org/10.5406/amerjpsyc.128.1.0089

Vega-Mendoza, M., West, H., Sorace, A., & Bak, T. H. (2015). The impact of late, non-balanced bilingualism on cognitive performance. *Cognition*, *137*, 40-46. https://doi.org/10.1016/j.cognition.2014.12.008

Verreyt, N., Woumans, E., Vandelanotte, D., Szmalec, A., & Duyck, W. (2016). The influence of language-switching experience on the bilingual executive control advantage. *Bilingualism: Language and Cognition*, *19*(1), 181-190. https://doi.org/10.1017/S1366728914000352

Wasylyshyn, C., Verhaeghen, P., & Sliwinski, M. J. (2011). Aging and task switching: A meta-analysis. *Psychology and Aging*, *26*(1), 15-20. https://doi.org/10.1037/a0020912

Wiseheart, M., Viswanathan, M., & Bialystok, E. (2016). Flexibility in task switching by monolinguals and bilinguals. *Bilingualism: Language and Cognition*, *19*(1), 141-146. https://doi.org/10.1017/S1366728914000273

Yow, W. Q., & Li, X. (2015). Balanced bilingualism and early age of second language acquisition as the underlying mechanisms of a bilingual executive control advantage: Why variations in bilingual experiences matter. *Frontiers in Psychology*, *6*, 164. https://doi.org/10.3389/fpsyg.2015.00164