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The Time Course of a Bilingual Stroop Task

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THE TIME COURSE OF A BILINGUAL STROOP TASK

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THE TIME COURSE OF A BILINGUAL STROOP TASK

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ABSTRACT

The purpose of the current study was to analyze the continuous dynamics of a bilingual Stroop task (between and within languages, and in proficient bilinguals’ first and second languages, L1 and L2, respectively). Understanding the time course of a bilingual Stroop task provides new insights regarding current theories of the bilingual mind. As found previously, interference emerged before facilitation and these effects were stronger within languages and in L1. Interestingly, mouse-tracking data showed (1) different time courses for the two Stroop processes (i.e., interference emerged earlier than facilitation), (2) different time courses within and between languages (i.e., within-languages effects emerged earlier than between-languages effects), and (3) different time courses for L1 and L2 (i.e., L1 effects emerged earlier than L2 effects). The present results add to the literature by exploring, for the first time, the temporal dynamics of the bilingual Stroop effects.
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CHAPTER I

INTRODUCTION

The present study is framed within the context of the general research question: Are bilingualism and aging two opposite forces on the same process? On the one hand, according to the Inhibition Deficit Theory (Hasher & Zacks, 1998), younger adults are better than older adults at inhibiting distracting responses. On the other hand, according to the Bilingual Advantage Theory (Bialystok, 1999), bilinguals inhibit better than monolinguals, not only in language related tasks but also in non-verbal tasks (Bialystok & Martin, 2004). The present study focuses on young bilinguals as a starting point for future research in which aging will be examined alongside bilingualism. Future work will examine all four groups (younger monolinguals, younger bilinguals, older monolinguals, and older bilinguals). Examining how language processes differ between younger and older adults, as well as bilinguals and monolinguals, can provide new insights in the study of cognitive reserve.

Stern (2002) defined cognitive reserve as the ability to use alternate paradigms to approach a problem when the more standard approach is no longer operational.
Cognitive reserve is a potential mechanism for coping with brain damage, and it could protect against dementia (e.g., Stern, 2002). This mechanism builds up from extended experience with stimulating activities, such as speaking two or more languages. Bilingualism appears to be one of many possible ways of enhancing cognitive reserve in order to minimize cognitive decline and delay the onset of various types of dementia (Bialystok, Craik, & Freedman, 2010; Mekala et al., 2013).

In communicating these findings to the general public, programs like “Lumosity” (Scanlon, Sarkar, & Drescher, 2007) have demonstrated how these results can be useful for implementing training programs to improve brain health. Most of these training programs include a series of exercises that have no direct connection to the user’s everyday activities. I argue that training in the use of a second language could have similar (perhaps even more profound) beneficial effects, while simultaneously increasing the user’s proficiency in a useful skill with real world applications (traveling, job opportunities, personal growth, metacognition, etc.). The potential for bilingualism to delay dementia was supported in a Canadian study in which bilinguals showed signs of dementia four years later than monolinguals (Bialystok et al., 2010). These findings have been recently replicated in India (Mekala et al., 2013), where bilinguals in the study developed dementia five years later than monolinguals. Moreover, the effect was even larger when focusing on illiterate bilinguals and monolinguals; the illiterate bilinguals developed dementia six years later than the illiterate monolinguals. These findings are consistent with the idea that cognitive reserve is at the root of these differences.

A report from the Alzheimer’s Association, “Changing the Trajectory of Alzheimer’s Disease: A National Imperative” (2010) shows that “the cumulative costs of
care for people with Alzheimer’s from 2010 to 2050 will exceed $20 trillion, in today’s dollars”. A treatment breakthrough that delayed the onset of Alzheimer’s Disease would result in immediate benefits for our society. Given the current life expectancy, a five year delay in the onset of the symptoms could cut the life of the disease in half (Alzheimer’s Association, 2010). By studying language development in bilingual and aging populations, it will be possible to obtain a deeper understanding of the issue. By all accounts, younger bilinguals should be best at inhibiting distracting information, and the older monolinguals should be the worst at doing so. The most intriguing groups in this research are the younger monolinguals and the older bilinguals. These groups will allow me to examine whether it is “better” to be young or to be bilingual, where better here of course refers to the ability to inhibit distracting information. If being bilingual is better, then the older bilingual group should demonstrate that the effect of bilingualism is sufficiently powerful to offset the aging process. If so, an extension of this research would be to examine whether the advantage that emerges from bilingualism can be found when implemented into a training program.

*The Stroop Effect*

Stroop’s (1935) article is one of the most influential studies in experimental psychology; currently cited over 12,000 times, including more than 1,000 citations in 2013 (Google Scholar). In Experiment 2 of Stroop’s original study, he introduced the “naming color test”, a task in which participants were presented with a color word (e.g., *blue*) and were instructed to respond to its ink color. In this color-naming task, participants responded more slowly and less accurately when the ink color and word meaning were incongruent (e.g., *red* in blue ink) compared to when the name of the color
appeared in black ink. This effect — the so-called Stroop effect — has widespread theoretical and practical significance. Although Stroop (1935) never used color words in congruent ink colors (e.g., blue in blue ink), there are many instances in the literature where the Stroop effect is defined as the difference between the congruent and incongruent conditions (without a proper control condition). This alteration essentially changed the nature of the task, because the original Stroop task only captured interference between ink color and word meaning, whereas the subsequent modified version also involves possible facilitation of information processing due to the congruence of ink color and word meaning. To achieve a clearer understanding of the Stroop task, I measured facilitation and interference separately in the present study by comparing each condition (congruent and incongruent) to a control condition.

In order to answer my research questions, a comprehensive framework for bilingual processing is needed, but first it is important to clarify the mechanisms underlying the Stroop effect. Two competing theories have been proposed: (1) there is a single processing mechanism underlying facilitation and interference (Roelofs, 2010) or (2) there are separate mechanisms (MacLeod & MacDonald, 2000), one for facilitation and one for interference. The converging information hypothesis (e.g., Cohen et al., 1990; Melara & Algom, 2003; Roelofs, 2003, 2010) supports the single process mechanism and corresponds to the coactivation framework; while the inadvertent reading hypothesis (e.g., Kane & Engle, 2003; MacLeod & MacDonald, 2000) is based on the assumption that there are separate mechanisms. Previous research (Incera, Yamamoto, & McLennan, 2014) has clearly showed that color naming and word reading interact with each other while the response is being formed. That is, a simple race model (i.e., there are
two separate processes and the faster of the two entirely controls the response) is clearly rejected; such a model cannot explain facilitation in the word reading task (i.e. reverse Stroop). Nevertheless, previous research (Incera et al., 2014) also provided evidence that interference emerges earlier than facilitation, supporting the assumption that there are separate mechanisms for interference and facilitation. In sum, theories that support the single process mechanism (i.e., converging information) would have to be extended to explain the differences in time course between facilitation and interference; theories that support separate mechanisms (i.e., inadvertent reading) would have to be extended to explain the interaction between color naming and word reading.

The present study is situated within connectionist models of the Stroop effect (e.g., Cohen et al., 1990; Melara & Algom, 2003; Roelofs, 2003). In this framework, different sources of information (e.g., word meaning and color) are simultaneously activated in a continuous fashion (Spivey, 2007), and facilitation and interference effects emerge from this interaction (although not necessarily at the same time). I predict that both interference and facilitation effects will emerge. Moreover, according to previous research (Incera et al., 2014) the time courses of interference and facilitation will be different. More specifically, I predict an earlier – and relatively stronger – interference effect, and a later – and relatively weaker - facilitation effect.

*Mouse Tracking*

To my knowledge, the current experiment is the first to use the dynamic mouse-tracking paradigm (Spivey, Grosjean, & Knoblich, 2005) to study the time course of facilitation and interference in a bilingual Stroop task. In particular, I used mouse-
tracking data to analyze when interference and facilitation effects emerge in the two languages of a bilingual. Previous Stroop studies have been limited by the lack of a continuous measure, making it impossible to directly observe the time course of the response. Researchers have used stimulus onset asynchronies (SOAs) to infer when the effects emerge (Roelofs, 2010). When using SOAs, several responses have to be compared in order to understand the timing of the effects; however, using mouse tracking, I directly observed each particular response over time, a more precise measure of the time course.

In 2010, Freeman and Ambady introduced MouseTracker, software designed to examine real time processing. Mouse-tracking data allowed me to evaluate the continuous dynamics of facilitation and interference, rather than relying on traditional end-point measures, such as reaction time (RT) or accuracy. With this new methodology, it is possible to observe the moment at which each process (facilitation and interference) is influencing the trajectory. Mouse tracking allowed us to measure the time course (e.g., how fast you move) and the intensity (e.g., how straight you move) of these effects separately. The potential to measure when the effects emerge and the intensity of the effects separately has important theoretical and practical implications. By measuring the online dynamics of the two languages, mouse-tracking data make it possible to discriminate between different theoretical accounts and provide new insights into the underlying debate regarding the organization of the bilingual mind.
Within vs. Between

In the bilingual Stroop task, the languages used for the stimuli can match (within) or mismatch (between) the language used for the response. Interference between the two languages of a bilingual, although not as great as that within either one of the languages, is quite robust (MacLeod, 1991). Facilitation within (red-red) and between (rojo-red) languages can be measured, as well as interference within (red-blue) and between (rojo-blue) languages. Previous research on the bilingual Stroop effect has focused on interference. MacLeod (1991) reported that interference between the two languages of a bilingual is typically about 75% of within-language interference. For example, if clicking the response button BLUE while being distracted by the word “red” led to 100 errors, then being distracted by the word “rojo” would lead to only 75 errors. Nevertheless, Preston and Lambert (1969) argued that when comparing performance within and between languages, results show that the Stroop effect in the between-languages situation is as large as in the within-language situation in some cases. In 1971, Dyer found that color naming was slowest when the naming language and the language of the color names was the same, although considerable interference also occurred when they differed. It has been argued (Marian & Spivey, 2003) that the magnitude of the interference may be mediated by a number of factors, such as stimuli, language background, and language mode. Language mode refers to the language or languages that are currently activated in the bilingual’s mind. For example, after a period of time talking and thinking in English, a bilingual person is in an “English mode.” When a bilingual switches between the two languages, both languages become salient; having both languages activated is considered being in a “bilingual mode.” The experimental
design can influence the language mode; for example, randomizing both languages within each block will result in participants being in bilingual mode. Nevertheless, when bilinguals perform in a “bilingual mode” (Grosjean, 1998) there is still a larger Stroop effect within than between languages (Marian & Spivey, 2003).

The Stroop effect is typically measured as the incongruent condition minus the congruent condition, thereby including facilitation and interference in the same measure. With this traditional measurement approach, Naylor, Stanley, and Wichal (2012) found a significant Stroop effect, both when the naming (i.e., identifying or naming the color in which the stimulus appeared) and reading languages were the same (within languages) and when they were different (between languages). The present experiment adds to the literature by measuring facilitation (congruent minus control) and interference (incongruent minus control) effects separately, both within and between languages. Given that between-language interference is generally stronger than within-language interference (e.g., MacLeod, 1991), I expect to find more robust interference and facilitation effects within languages than between languages.

**L1 vs. L2**

Interference (MacLeod, 1991) is affected by the participants’ relative proficiency in the two languages, and thus, not surprisingly, proficiency influences the magnitude of the Stroop effect (Magiste, 1985; Chen & Ho, 1986). Bilinguals with one dominant language experience greater interference when performing in the dominant language. Sumiya and Healy (2008) argued that less proficient bilingual speakers are less likely than more proficient bilinguals to have automatic access to the phonology of written
words in their second language (L2). The native language (L1) may be learned and used implicitly, relying upon automated cerebral mechanisms; by contrast, the L2, particularly if learned later in life, is probably learned and used explicitly, relying upon more conscious mechanisms (Avila, Gonzalez, Parcet, & Belloch, 2004). In the present task, the responses were always in English, but the language used for the stimuli was either the bilingual’s native (L1) or non-native (L2) language. Given that the experiment was conducted in an English speaking university, it is likely that most of our participants use English in their daily lives, and for some of the participants their native (e.g., Spanish) and dominant (e.g., English) languages might not be the same. In sum, because a native language has more potential for interfering than does a non-native one (MacLeod, 1991), I expect to find more robust interference and facilitation effects in participants’ L1 than in their L2.

Selective vs. Nonselective Activation

The purpose of the present experiment is to study the continuous dynamics of facilitation and interference of the bilingual participants’ two languages. Understanding the time course of the bilingual Stroop effect could help distinguishing between selective and nonselective activation theories. These traditional views of bilingualism translate to different predictions regarding the time course of cognitive processing. In a language-specific view, each language would be selectively accessed; therefore, facilitation and interference processes should emerge at different times for each language (e.g., later for the weaker language). On the contrary, a nonselective activation account would predict simultaneous access to both languages, and no time course differences would emerge. These traditional views would translate in specific predictions for mouse-tracking data.
If the trajectories for both languages deviate from the control trajectory at the same time, our data would support the nonselective activation account. If the trajectory for the stronger language deviates from the control earlier than the trajectory for the weaker language, our data would support the language-specific view. Nevertheless, it is important to point out that the present experiment cannot definitively distinguish between these two competing views.

The present study can provide new insights about the time course of these cognitive processes, but it cannot definitively reject the assumptions of either view. The reason for this lack of conclusive results is that simultaneous access to both languages does not mean that both languages are processed at the same rate. In other words, both languages might be active at the same time but one language might be processed faster than the other resulting in apparent separate activation of the two languages. This argument is based on the “temporal delay assumption” (Dijkstra & Van Heuven, 2002, p. 183) of the BIA+ model. Dijkstra and Van Heuven (2002) argued that when orthographic representations become active, these orthographic representations start to activate associated phonological and semantic representations; but these representations of both languages are activated slightly later than the orthographic representation. Therefore it is possible for a nonselective activation account to result in different time courses for the two languages, depending on the levels of activation of each language. These levels of activation will depend on many factors. For example, differences in the task (within vs. between languages), the participant (L1 vs. L2), or the stimuli (high or low phonological overlap between languages) will likely affect the time course of facilitation and interference in the context of the Stroop task.
The question of whether bilinguals activate their two languages selectively or in parallel has generated much interest in the bilingual research community (Marian & Spivey, 2003). It is important to understand whether the bilingual lexicon has a language-specific organization, having independent or modular lexical memory stores for each known language, or a language-nonspecific organization, having an integrated lexical memory store containing all known words in both languages (Libben & Titone, 2009). Nevertheless, Marian and Spivey (2003) argued that it is important to take into account changes that take place over time, and that it would be a mistake to think that there is a ‘yes’ or ‘no’ answer to the parallel versus selective activation question. The question is no longer if one language can be completely deactivated. In general, research has supported the nonselective activation account (Grainger & Beauvillain, 1987; Grainger, 1993; Marian & Spivey, 2003; Libben & Titone, 2009), according to which both languages are simultaneously activated. The new questions are concern with the level of these activations. To what extent is each language activated? What are the factors influencing this activation? How can this activation influence the time course of the response? For example, research has shown that fine-grained acoustic-phonetic information and a precise match between input and representation are critical for parallel activation of two languages (Ju, & Luce, 2004).

Predictions

The present study adds to the literature in two novel ways. First, the current study expands the conclusions from previous research in bilingual interference (MacLeod, 1991; Marian and Spivey, 2003) and facilitation (Roelofs, 2010) effects, by including a control condition. Second, the current study measures the time course of the effects,
which offers an innovative method for understanding cognitive processes as they unfold over time.

(A) Following previous research:

- An earlier and stronger interference effect will emerge, relative to the facilitation effect.
- Both interference and facilitation effects will be more robust in the within-languages condition than in the between-languages condition.
- Both interference and facilitation effects will be more robust in participants’ L1 than in their L2.

(B) Distinguishing between traditional competing theories (see Figure 1):

- If the data support the selective activation account, then within (and L1) trajectories will separate from the control earlier than between (and L2) trajectories.
- If, on the contrary, the data support the nonselective activation account, then within (and L1) and between (and L2) trajectories will separate from the control at the same time.

The logic behind these predictions is that if nonselective activation on both languages occurs, participants should be influenced by both languages at the same time. On the contrary, if both languages are selectively activated; within (and L1) should be accessed first, resulting in earlier effects of interference and facilitation relative to between (L2).
Figure 1 contains hypothetical data patterns in order to illustrate the predicted patterns of results. In Figure 1, the vertical axis represents the x-coordinate (the mouse starts at 0, the correct response is situated at 1, and the incorrect response at -1), while the horizontal axis represents time (the first 1,000ms of the trajectory). The blue line is the average of the control trajectories, the orange lines represent interference, and the green lines correspond to facilitation. The solid lines are participants’ within (and L1) trajectories, while the discontinuous lines are between (and L2) trajectories. In particular, Figure 1 illustrates that, according to selective access, the effects of facilitation and interference occur at different points in time (i.e., earlier within than between, and earlier in L1 than in L2), and according to nonselective access, the effects of facilitation and interference occur at the same time within as between (and in L1 as in L2).
Figure 1. Hypothetical data patterns illustrating the predicted patterns of results according to Selective and Nonselective Activation accounts.
CHAPTER II

METHOD

Participants

I recruited 20 bilingual participants from the Cleveland State University community, including the Psychology Department participation pool. All participants were fluent Spanish-English bilinguals, received credit (0.5) for their participation, and were less than 30 years old (M = 21, SD = 3.2); 17 of the 20 participants were right-handed. The pattern of results was the same with and without the left-handed participants; therefore I included them in the final analysis. I used participants’ self-reported first language as the basis for assigning each participant to the English or Spanish native group. Previous research has shown strong correlations between self-reported measures of proficiency in each language and objective measures of language-dominance (Gollan et al., 2012).

Measures

MouseTracker records the trajectory of the mouse every 13 to 17 milliseconds (ms). Three pieces of information are recorded (Freeman & Ambady, 2010): raw time
(how many ms have elapsed), the $x$-coordinate of the mouse (in pixels), and the $y$-coordinate of the mouse (in pixels). According to Freeman and Ambady (2010), all trajectories are rescaled into a standard coordinate space. The top left corner of the screen corresponds to [-1.00, 1.50], and the bottom right corner corresponds to [1.00, 0.00], leaving the starting location of the mouse (the bottom center) with the coordinates [0.00, 0.00].

MouseTracker provides many measures that can be interpreted in different ways. In the present paper I analyzed only three of all the possible measures (see Table 1, selected measures in bold). Each of the selected measures provides different information about the mental processes involved in performing the task. AUC relates to the amount of inhibition, RT is a measure of speed of processing, and X-coordinate provides information about the time course of the response.

Table 1. Dependent Variables.

<table>
<thead>
<tr>
<th>Trajectory</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall</strong></td>
<td></td>
</tr>
<tr>
<td>- Area Under the Curve (AUC)</td>
<td>- Reaction Time (RT)</td>
</tr>
<tr>
<td>- X Flips</td>
<td>- Initiation Time</td>
</tr>
<tr>
<td>- Maximum Deviation</td>
<td>- Maximum Deviation Time</td>
</tr>
<tr>
<td><strong>Online</strong></td>
<td></td>
</tr>
<tr>
<td>- X Coordinate</td>
<td>- Velocity</td>
</tr>
</tbody>
</table>

Reaction Time (RT) is measured from the onset of the target stimulus (clicking START) to the onset of the final response (clicking the response box). Area Under the Curve (AUC) and Maximum Deviation (MD) are standard measures in mouse-tracking (Spivey et al., 2005). According to Freeman and Ambady (2010), the amount of spatial
attraction toward an unselected response (i.e., MD and AUC) is calculated by comparing the trajectory with an idealized response trajectory (straight line). Freeman, Ambady, Rule and Johnson (2008) found that using the MD versus the AUC for the same data does not substantially change the results; however, AUC is a better index of the overall attraction toward the unselected alternative (incorporating all time steps). Maximum Deviation Time (MD Time) is calculated as the duration between the onset of the target stimulus and the Maximum Deviation point, the moment at which the trajectory is the farthest from the ideal trajectory. Initiation Time (InitTime) is the duration between the onset of the target stimulus and the initiation of mouse movement. It is important to emphasize that initiation times need to be equivalent in order to avoid confounding accounts of the data based on differences in motor processes. If initiation times are equivalent across conditions, then any differences in the dependent variables are presumably due to differences in response selection (i.e., cognitive processes) as opposed to response execution (motoric processes).

Online measures include X-Coordinate (X) and Velocity (V) that can be analyzed in multiple ways. A common method is dividing the trajectory in different time bins, and including time as a factor in an ANOVA. Another possibility is performing Monte Carlo simulations based on the data from the experiment (see e.g., Dale, Kehoe, & Spivey, 2007; see also, Incera et al., 2014). Following this technique, 10,000 sets of simulated data are randomly generated, as though the same experiment were repeated 10,000 times. When generating these data, it is assumed that, for every time bin, the simulated data would follow the same normal distributions that the actual experimental data produced. This assumption is necessary to account for the continuous properties of the mouse
trajectories; generating totally random data would not be appropriate because in mouse
trajectories contiguous data points are more likely to have similar x-coordinates than
distant data points. A threshold is defined as the smallest amount of consecutive time
bins that appeared less than 500 times in the 10,000 simulated experiments (i.e.,
$500/10,000 = .05$). When a sequence of significant time bins in the actual experimental
data is longer than this threshold, the chance of its happening by chance should be less
than .05.

The Language Questionnaire (Appendix 1) was used to record a range of
information about the bilingualism of the participants in order to measure L1 and L2
proficiencies, frequency of usage, frequency of code switching (how often the
participants change between languages), onset age of active bilingualism, language
history, language stability, function of languages, and the language mode. Based on Tse
and Altarriba (2012), participants separately rated, from 0% to 100%, how closely their
L1 and L2 proficiencies are relative to native speakers in four language skills
(comprehension, speaking, reading, and writing). The questionnaire was presented in
both English and Spanish in order to stimulate a bilingual mode and memory processes
associated with both languages.

**Stimuli**

Following Klein (1964) and Roelofs (2010), I used four color words (BLUE,
GREEN, RED, YELLOW). Each color word was presented in Spanish and English.
Each participant responded to a total of 80 experimental trials and eight practice trials.
First, the practice trials included two trials each of red, green, yellow and blue color
patches (Roelofs, 2010). Second, the 16 control trials were four trials each of a series of X’s, M’s, H’s, or S’s (e.g., XXXX), presented in a separate block at the beginning of the experiment. Finally, there were four target conditions (congruent-Spanish, congruent-English, incongruent-Spanish, incongruent-English) with 16 trials each. For each language, there were 16 trials in the incongruent condition (e.g., red, rojo in the color blue) and 16 in the congruent condition (e.g., red, rojo in the color red).

**Design**

There were two within-participants factors (Condition: congruent, incongruent, control; Language: English, Spanish). Following Roelofs (2010), I used eight congruent pairings (Spanish ROJO-red, AZUL-blue, AMARILLO-yellow, VERDE-green, and English RED-red, BLUE-blue, YELLOW-yellow, GREEN-green), and 24 incongruent pairings (Spanish ROJO-blue, ROJO-yellow, ROJO-green, etc., and English RED-blue, RED-yellow, RED-green, etc.). For each of the four versions of the experiment, 16 congruent (each color presented four times) and 16 incongruent (counterbalanced across versions) pairings were presented in Spanish and English (total of 64 pairings).

Paired response alternatives (“BLUE  GREEN”; “RED  YELLOW”) appeared in the top left and right corners of the screen. In order to counterbalance response options (all four colors in all four response positions) there were four versions of the experiment. Each version had eight practice trials at the beginning of the experiment, followed by a control block with the 16 control stimuli. I presented the control trials at the beginning of the experiment in a separate block in order to ensure that the control condition was not affected by general activation or carryover effects from the target conditions. After the
control trials, the experimental block was presented with the random presentation of the English and Spanish congruent and incongruent trials, in order to stimulate bilingual mode. I decided to mix the experimental conditions in one block in order to stimulate bilingual mode. Roelofs (2010) found Stroop facilitation and interference effects when language trials were randomized together, not only within language, but also between languages. Nevertheless, either decision could be appropriate; Roelofs (2010) found the same pattern of results with English and Spanish trials in different blocks.

Procedure

Participants were tested individually in the Language Research Laboratory. Participants answered pages 1 and 2 of the Participant Information Form (Appendix 2), and signed two copies of the Participants Consent Form (Appendix 3). The experiment was conducted on a standard PC. Using MouseTracker (Freeman & Ambady, 2010), each participant was randomly assigned to one of the four versions of the experiment that counterbalanced all four colors in all four response positions. As in the original color-naming task (Stroop, 1935), participants were instructed to ignore the content of the word (or letters) and to click on the color in which the word (or letters) were printed as quickly and accurately as possible. At the beginning of each trial “START” appeared at the bottom-center, and the response options appeared in the top left and right corners. Upon clicking “START”, the target word appeared in the center; target words were presented in random order. Participants were instructed to begin moving the mouse immediately after clicking “START”. If a participant took more than 500ms to initiate a mouse movement, a warning appeared at the end of that trial instructing the participant to start moving the mouse earlier on future trials. Once the participant finished all 88 trials on
MouseTracker, the researcher opened the Language Questionnaire using the SuperLab software package (Cedrus Corporation, Cleveland OH). This questionnaire recorded a range of information about their bilingualism, as shown in Appendix 1. First, questions about their proficiency in English and about their bilingualism were presented in English. Second, questions about their proficiency in Spanish were presented in Spanish. Once the experiment ended, participants answered the Post-Experiment Questionnaire (Appendix 4) and were given the Post-Experiment Information Form (Appendix 5).
As discussed in the Methods section, the mouse-tracking paradigm provides a wide range of dependent measures. As a starting point, I compared initiation times in all conditions. Equivalent initiation times across conditions would provide evidence that any obtained differences in the other dependent measures are due to differences in cognitive processes, and not to response execution differences in motor movements. Then, I focused on three different measures in order to answer my research questions. First, to allow for a direct comparison with previous studies, I analyzed (1) RTs as a function of condition. Second, to further investigate these effects, I analyzed (2) AUC, a highly sensitive measure specific to the mouse tracking paradigm, as a function of condition. Third, in order to study the time course of the two languages, I analyzed (3) $x$-coordinate over time by comparing the average trajectory of each experimental condition to the average trajectory of the control.
Data Screening

There were a total of 80 target trials (16 per condition), for a grand total of 1600 trajectories across participants (360 per condition). Consistent with previous research (Incera, Markis, & M’Lennan, 2013; Krestar, Incera & M’Lennan, 2013), incorrect responses and initiation times greater than 500 ms were discarded. Additionally, aberrant responses (erratic, non-interpretable trajectories looping leftward and rightward) were discarded (Freeman & Ambady, 2010). Overall, 87% of the trials were included in the final analyses (see Table 2), 80% of the incongruent trials and 92% of the congruent and control trials. These results are consistent with previous Stroop experiments in mouse tracking that included 91% of the trials, 88% inclusions in incongruent trials and 96% in congruent trials (Incera et al., 2013). Nevertheless, we found the same patterns of results without the deletions. Effect sizes and 95% confidence intervals (CIs) are reported throughout (Cummings, 2012).
Table 2. Data Screening. Number of trials remaining after excluding incorrect responses, initiation times longer than 500 ms, aberrant trials, and final percent of trials included in the analysis (for every experimental condition and the total average).

<table>
<thead>
<tr>
<th></th>
<th>Incongruent</th>
<th>Incongruent</th>
<th>Control</th>
<th>Congruent</th>
<th>Congruent</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>English</td>
<td>Spanish</td>
<td></td>
<td>Spanish</td>
<td>English</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>320</td>
<td>320</td>
<td>320</td>
<td>320</td>
<td>320</td>
<td>1600</td>
</tr>
<tr>
<td>Excluding Incorrect</td>
<td>291</td>
<td>303</td>
<td>318</td>
<td>317</td>
<td>319</td>
<td>1488</td>
</tr>
<tr>
<td>Excluding Init Times &gt; 500ms</td>
<td>284</td>
<td>294</td>
<td>316</td>
<td>314</td>
<td>311</td>
<td>1519</td>
</tr>
<tr>
<td>Excluding Aberrant</td>
<td>249</td>
<td>262</td>
<td>293</td>
<td>294</td>
<td>299</td>
<td>1397</td>
</tr>
<tr>
<td>Included</td>
<td>78%</td>
<td>82%</td>
<td>92%</td>
<td>92%</td>
<td>93%</td>
<td>87%</td>
</tr>
</tbody>
</table>

Within vs. Between

All response alternatives were presented in English; therefore, the English stimuli represent the within-language condition, while the Spanish stimuli represent the between-languages condition. Even though English proficiency (91%) was slightly higher than Spanish proficiency (82%), the difference was not statistically significant, $t(19) = 1.72, p = .10, d = 0.68$.

For *Initiation Times*, an ANOVA with five levels (Incongruent within, Incongruent between, Control, Congruent between, and Congruent within) revealed no significant differences ($F(4, 76) = 1.01, MSE = 1529.72, p = .41, \eta^2_p = .05$) between the
five conditions. Consequently, I can rule out response execution differences in motor movements as the locus of any differences obtained in the other dependent measures.

In Reaction Times, following the traditional analysis of the Stroop effect (i.e., congruent vs. incongruent), I performed a 2 Stroop (congruent, incongruent) X 2 language (within, between) repeated measures ANOVA. There was a significant interaction ($F(1, 19) = 7.43, \text{MSE} = 35,133.85, p = .01, \eta^2_p = .28$) and a significant Stroop effect ($F(1, 19) = 21.2, \text{MSE} = 456,689.81, p < .001, \eta^2_p = .53$), but no main effect of language ($F(1, 19) < 1.0, \text{MSE} = 1,021.01, p = .75, \eta^2_p = .01$). The interaction was driven by the fact that within languages there was more interference (i.e., slower incongruent trials) and more facilitation (i.e., faster congruent trials) than between languages.

Next, I compared the congruent and incongruent conditions for within and between languages to the control condition (see Table 3 and Figure 2). These comparisons allowed for the separate analysis of facilitation and interference effects. There was a significant interference effect within ($t(19) = 3.55, p = .001, d = 0.67$) and between ($t(19) = 2.66, p = .008, d = 0.48$) languages; but no significant effects of facilitation within ($t(19) = 0.58, p = .57, d = 0.09$) or between ($t(19) = 0.46, p = .65, d = -0.07$) languages.
Table 3. RTs in milliseconds as a function of Language and Condition. Measures of facilitation (congruent minus control) and interference (incongruent minus control) within and between languages.

<table>
<thead>
<tr>
<th></th>
<th>RT Mean (SD)</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Congruent</td>
<td>Incongruent</td>
</tr>
<tr>
<td>Within</td>
<td>1051 (221)</td>
<td>1244 (298)</td>
</tr>
<tr>
<td>Between</td>
<td>1086 (235)</td>
<td>1195 (297)</td>
</tr>
</tbody>
</table>

* p < .05

Figure 2. Reaction Times measures (in ms) of control (blue bar), facilitation (green bars) and interference (orange bars). Interference and facilitation measures were either within (darker green and orange) or between (lighter green and orange) languages. Error bars represent confidence intervals (CIs) at 95%.
For *Area Under the Curve*, following the traditional analysis of the Stroop effect (i.e., congruent vs. incongruent), I performed a 2 Stroop (congruent, incongruent) X 2 language (within, between) repeated measures ANOVA. There was a significant Stroop effect (F(1, 19) = 17.35, MSE = 11,675, p = .001, ηp² = .48), but no interaction (F(1, 19) = 2.48, MSE = .15, p = .13, ηp² = .12) or main effect of language (F(1, 19) < 1.0, MSE = .05, p = .61, ηp² = .01).

Next, I compared the congruent and incongruent conditions for within and between languages to the control condition (see Table 4 and Figure 3). These comparisons allowed for the separate analysis of facilitation and interference effects. The interference effect was significant within (t(19) = 3.20, p = .003, d = 0.85) and between (t(19) = 2.82, p = .006, d = 0.76) languages. Unlike in the RT analyses, the facilitation effect was significant within (t(19) = 2.31, p = .016, d = 0.58), and marginally significant between (t(19) = 1.58, p = .065, d = 0.45) languages.
Table 4. AUC as a function of Language and Condition. Measures of facilitation (congruent minus control) and interference (incongruent minus control) within and between languages.

<table>
<thead>
<tr>
<th></th>
<th>AUC Mean (SD)</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Congruent</td>
<td>Incongruent</td>
</tr>
<tr>
<td>Within</td>
<td>0.61 (0.38)</td>
<td>1.46 (0.94)</td>
</tr>
<tr>
<td>Between</td>
<td>0.65 (0.46)</td>
<td>1.32 (0.79)</td>
</tr>
</tbody>
</table>

* *p < .05

Figure 3. Area Under the Curve measures of control (blue bar), facilitation (green bars) and interference (orange bars). Interference and facilitation measures were either within (darker green and orange) or between (lighter green and orange) languages. Error bars represent CIs at 95%. 

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For *x-coordinate*, I compared the congruent and incongruent conditions, within and between languages, to the control condition (see Figure 4). First, the within-languages interference effect emerged in 29 significant contiguous *t* tests between 420 and 1000 ms. The threshold was 14 contiguous *t* tests, therefore the effect was significant. Second, the between-languages interference effect emerged in 25 significant contiguous *t* tests between 500 and 1000 ms. The threshold was 14 contiguous *t* tests; therefore, the effect was significant. Third, the within-languages facilitation effect emerged in 12 significant contiguous *t* tests between 620 and 860 ms. The threshold was 10 contiguous *t* tests; therefore, the effect was significant. Fourth, the between-languages facilitation effect did not emerge in any time bin.

*Figure 4.* The *x*-coordinates of the mouse position over time for the mean facilitation (green), interference (orange), and control (blue) trajectories. Interference and facilitation were either within (solid lines) or between (discontinuous lines) languages.
There were 15 English and 5 Spanish native participants. The L1 condition includes the English trials of the English native participants and the Spanish trials of the Spanish native participants. The L2 condition includes the English trials of the Spanish native participants and the Spanish trials of the English native participants. The average proficiency in the L1 (97%) was significantly higher than the average proficiency in L2 (76%) ($t(19) = 6.06, p < .001, d = 2.10$).

For *Initiation Times*, I performed an ANOVA with five levels (Incongruent L1, Incongruent L2, Control, Congruent L2, and Congruent L1). There were no significant differences ($F(4, 76) < 1.0, MSE = 1969.40, p = .59, \eta_p^2 = .04$) between the five conditions. Consequently, I can rule out response execution differences in motor movements as the locus of any differences obtained in the other dependent measures.

For *Reaction Times*, following the traditional analysis of the Stroop effect (i.e., congruent vs. incongruent), I performed a 2 Stroop (congruent, incongruent) X 2 language (L1, L2) repeated measures ANOVA. There was a significant Stroop effect ($F(1,19) = 40.39, MSE = 456,689.81, p < .001, \eta_p^2 = .68$), but no significant interaction ($F(1, 19) = 1.54, MSE = 23.873.25, p = .23, \eta_p^2 = .08$) or main effect of language ($F(1, 19) < 1.0, MSE = 147.39, p = .98, \eta_p^2 < .001$).

Next I compared the congruent and incongruent conditions for L1 and L2 with the control condition (see Table 5 and Figure 5). These comparisons allowed for the separate analysis of facilitation and interference effects. The only significant effect was interference in L1 ($t(19) = 1.95, p = .03, d = 0.65$), although interference in L2 was
marginally significant ($t(19) = 1.60, p = .063, d = 0.50$). There were no significant facilitation effects in L1 ($t(19) = 0.26, p = .80, d = 0.09$) or in L2 ($t(19) = 0.21, p = .84, d = -0.06$).

Table 5. RTs in milliseconds as a function of Language and Condition. Measures of facilitation (congruent minus control) and interference (incongruent minus control) in L1 and L2.

<table>
<thead>
<tr>
<th></th>
<th>RT Mean (SD)</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Congruent</td>
<td>Incongruent</td>
</tr>
<tr>
<td>L1</td>
<td>1053 (201)</td>
<td>1238 (294)</td>
</tr>
<tr>
<td>L2</td>
<td>1085 (253)</td>
<td>1201 (301)</td>
</tr>
</tbody>
</table>

*p < .05
Figure 5. Reaction Times measures (in ms) of control (blue bar), facilitation (green bars) and interference (orange bars). Interference and facilitation measures were either in L1 (darker green and orange) or in L2 (lighter green and orange). Error bars represent 95 % CIs at 95%.

For Area Under the Curve, following the traditional analysis of the Stroop effect (i.e., congruent vs. incongruent), I performed a 2 Stroop (congruent, incongruent) X 2 language (L1, L2) repeated measures ANOVA. There was a significant Stroop effect (F(1,19) = 43.49, MSE = 11,675, p < .001, ηp2 = .70), but no significant interaction (F(1,19) < 1.0, MSE = .168, p = .56, ηp2 = .02) or main effect of language (F(1,19) < 1.0, MSE = .31, p = .50, ηp2 = .03).

Next I compared the congruent and incongruent conditions for L1 and L2 with the control condition (see Table 6 and Figure 6). These comparisons allowed for the separate analysis of facilitation and interference effects. The interference effect was significant for both L1 (t(19) = 3.11, \( p = .003, d = 0.92 \)) and L2 (t(19) = 2.61, \( p = .009, d = 0.69 \)). The facilitation effect was significant for L2 (t(19) = 1.96, \( p = .03, d = 0.53 \)), and marginally significant for L1 (t(19) = 1.62, \( p = .061, d = 0.50 \)).

Table 6. AUC as a function of Language and Condition. Measures of facilitation (congruent minus control) and interference (incongruent minus control) in L1 and L2.

<table>
<thead>
<tr>
<th>AUC Mean (SD)</th>
<th>Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Congruent</td>
<td>Incongruent</td>
</tr>
<tr>
<td>Facilitation</td>
<td>Interference</td>
</tr>
</tbody>
</table>

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Figure 6. Area Under the Curve measures of control (blue bar), facilitation (green bars) and interference (orange bars). Interference and facilitation measures were either in L1 (darker green and orange) or in L2 (lighter green and orange). Error bars represent CIs at 95%.

For x-coordinate, I compared the congruent and incongruent conditions in L1 and L2 to the control condition (see Figure 4). First, the L1 interference effect emerged in 27 significant contiguous t tests between 460 and 1000 ms. The threshold was 26 contiguous t tests; therefore, the effect was significant. Second, the L2 interference effect emerged in 23 significant contiguous t tests between 540 and 1000 ms. The threshold was 21 contiguous t tests; therefore, the effect was significant. Finally, despite a general
facilitation trend at the end of the trajectories (see Figure 7), neither the L1 nor the L2 facilitation effects reached significance in any time bin.

Figure 7. The x-coordinates of the mouse position over time for the mean facilitation (green), interference (orange), and control (blue) trajectories. Interference and facilitation were either L1 (solid lines) or L2 (discontinuous lines).
The purpose of the current study was to analyze the continuous dynamics of a bilingual Stroop task. I argue that online measures allow us to observe the relative time at which interference and facilitation effects emerge, in both the within and between-languages conditions as well as in the L1 and L2 languages of a bilingual. Previous studies have made inferences based on traditional end point measures (e.g., accuracy, RTs), which answer questions such as: Is the effect stronger within than between languages? Is the effect stronger in L1 than in L2? Mouse-tracking data provide a richer analysis of the responses, making it possible to better understand the relative timing of the effects, and to answer new and exciting questions, such as: Is the time course the same within than between languages? Are L1 and L2 processed at the same time?

First, as previously reported using RTs (MacLeod, 1991), interference effects were stronger than facilitation effects. In RTs, the mean difference for interference was above 100 ms, while the mean difference for facilitation was below 20 ms. Despite the fact that the congruent conditions were roughly 20 ms faster than the control condition,
these effects were not statistically significant. Nevertheless, the greater sensitivity of AUC allowed significant (or marginally significant) facilitation effects to emerge in all conditions (i.e., within, between, L1, L2). Second, I replicated previous findings from the bilingual Stroop literature in which more robust interference effect emerges within than between languages. Moreover, the present experiment extended this effect to facilitation; I found a significant interaction, supporting the idea that within languages there was not only more interference (i.e., slower incongruent trials), but also more facilitation (i.e., faster congruent trials) than between languages. Third, a similar pattern emerged between L1 and L2. When comparing the incongruent to the control condition in L1 the effect was significant, but in L2 it was only marginally significant, supporting the idea that L1 interfered more than L2. Fourth, analyzing mouse trajectories provides new information on the time course of the effects. Interference emerged within (420 ms) and between (500 ms) languages; while facilitation emerged later (620 ms) and only within languages. Also, interference effects emerged earlier for L1 (460 ms) than L2 (540 ms).

As argued before, it would be a mistake to think that there is a ‘yes’ or ‘no’ answer to the parallel versus selective activation question (Marian & Spivey, 2003). The question is not only “if” both languages are activated, but also “to what extent” they are activated. When observing the time course of the interference effects, the effects emerged 80 ms earlier within than between languages, as well as in L1 than L2. The fact that the time periods for L1 and L2 generally overlapped but L1 emerged 80ms earlier than L2 supports the “temporal delay assumption” from the BIA+ model (Dijkstra & Van Heuven, 2002). According to Dijkstra and Van Heuven (2002) the phonological and semantic representations of a word are activated slightly later than the orthographic
representation because their activation will depend, among other factors, on subjective frequency. Bilinguals have been exposed to their L2 words less frequently than to their L1 words; therefore L2 interference will be delayed relative to L1. The temporal delay assumption conciliates non selective activation accounts of the two languages with temporal delays in L2 relative to L1. Nevertheless, according to Brysbaert, Van Wijnendaele, and Duyck (2002) it is not the case that the delay will be substantial and constant for all types of words only depending on the proficiency of the bilingual. Language mode (Grosjean, 1998) or phonological overlap between languages can also impact the time course (Brysbaert et al., 2002). Our results support this criticism to the temporal delay assumption; the effects emerged 80 ms later between languages (i.e., bilingual mode) than within languages (i.e., English mode). In sum, the present results support the “temporal delay assumption” of the BIA+ model, but taking into account that temporal delays can also be driven by factors other than proficiency (e.g., language mode).

In the present experiment, all response alternatives were presented in English. The English stimuli represent the within-language condition, while the Spanish stimuli represent the between-language condition. Therefore, there is a confound between the language used for stimulus presentation and the within vs. between manipulation. Based on previous research, I would not expect a different pattern of results if all response alternatives were presented in Spanish, but future research could solve this confound by presenting the response options as color patches, which would eliminate language and reading effects in the response. Another consequence of the confound between the language used for stimulus presentation and the within vs. between manipulation, is the
overlap between the within/between and L1/L2 effects. Even though I separately analyzed within/between and L1/L2 effects the responses were always in English; therefore, participants whose native language was English responded within languages in their L1, while Spanish native participants answered within languages in their L2. Another limitation of the current study is the continuous measures analysis. I performed a series of t tests, comparing the number of contiguous significant t tests to the threshold obtained in the simulations. While this method allows accurate conclusions regarding whether or not the effects are significant, and provides general information about when these effect emerge; this method does not allow for a statistical comparison of the timing of these effects. Further analyses will be necessary to better understand the time course of the bilingual mind.

Although previous research with mouse tracking has found differences as early as 350 ms (Incera et al., 2013), most of the effects reported in the current study emerged around 500 ms after stimuli onset. Previous research has argued that bilingual lexical access may be language-independent in the initial few hundred milliseconds (Marian & Spivey, 2003). Thus, it is possible that bilingual lexical access may be language-independent at early stages that were not captured in the current study. However, mouse movements in the current study were initiated between 100 and 150 ms after stimulus onset, which is similar to the initiation times in eye movements reported in the literature. Nevertheless, future research should combine these different techniques in order to better understand cognitive processes at every moment of the time course.

The present experiment adds to the literature in two novel ways. First, it expands the conclusions of the interference and facilitation effects in the Stroop task by including
the control condition. Second, it provides new insights in the time course of a bilingual Stroop task. Interestingly, mouse-tracking data showed (1) different time courses for the two Stroop processes (i.e., interference emerged earlier than facilitation), (2) different time courses within and between languages (i.e., within-languages effects emerged earlier than between-languages effects), and (3) different time courses for L1 and L2 (i.e., L1 effects emerged earlier than L2 effects). The different time courses between and within languages, as well as in L1 and L2, support the idea that different levels of proficiency and different language modes can result in temporal delays. Marian and Spivey (2003) argued that bilinguals experience competition from both languages and into both languages, although the magnitude of the effect changes under different circumstances (e.g., stimulus selection, participant selection, language mode, etc.). The current data show that not only the magnitude, but also the time course, of the effect changes under different circumstances. Current models of bilingual processing will have to incorporate these time course differences in order to better explain the cognitive processes of the bilingual mind. In sum, the present results add to the literature by exploring, for the first time, the temporal dynamics of the bilingual Stroop effects.
REFERENCES


APPENDICES

Appendix 1

LANGUAGE QUESTIONNAIRE
SARA INCERA, PH. D. STUDENT
LANGUAGE RESEARCH LABORATORY
CLEVELAND STATE UNIVERSITY: DEPARTMENT OF PSYCHOLOGY
CHESTER BUILDING 249-251
(216) 687-3834

1) English

Proficiency
Rate from 0% to 100%, how closely your reading proficiency in English is relative to native speakers.
Rate from 0% to 100%, how closely your listening proficiency in English is relative to native speakers.
Rate from 0% to 100%, how closely your writing proficiency in English is relative to native speakers.
Rate from 0% to 100%, how closely you speaking proficiency in English is relative to native speakers.

Frequency of usage
Rate from 0% to 100%, what percentage of your time you speak in English.

Frequency of code switching
Rate from 0% to 100%, what percentage of your time you speak only English every week.
Rate from 0% to 100% what percentage of your time you speak only English every day.
Language stability
Is your knowledge of English stable? Yes/No
Is your English still improving? Yes/No
Are you loosing skills in English? Yes/No

Language history
How old were you when you learned English?
How did you learn English?
Where did you learn English?
With whom did you learn English?

Function of languages
In which moments of your everyday life do you use English?
Where do you use English?
With whom do you speak English in your everyday life?

Are you bilingual? (If NO → End / If YES → Continue 2nd Part)

2) Bilingualism

Onset age of active bilingualism
At what age did you start to consider yourself bilingual?
What is your first language?
What is your second language?
Do you know or are you learning a third language?

Language mode
Rate from 0% to 100%, what percentage of your time you use both languages at the same time.
Rate from 0% to 100%, what percentage of your time you speak both languages every week.
Rate from 0% to 100% what percentage of your time you speak both languages every day.
Do you use both languages with the same people?
Do you use words from your first language when speaking your second language?
Do you use words from your second language when speaking your first language?

**Do you understand Spanish? (If NO → End / If YES → Continue 3rd Part)**

3) **Spanish**

**Proficiency**
Evalúa de 0% a 100% cómo es, respecto a un nativo, tu nivel de lectura en español.
Evalúa de 0% a 100% cómo es, respecto a un nativo, tu nivel para entender una conversación en español.
Evalúa de 0% a 100% cómo es, respecto a un nativo, tu nivel de escritura en español.
Evalúa de 0% a 100% cómo es, respecto a un nativo, tu nivel para participar en una conversación en español.

**Frequency of usage**
Evalúa de 0% a 100%, qué porcentaje de tu tiempo hablas en español.

**Frequency of code switching**
Evalúa de 0% a 100%, qué porcentaje de tu tiempo hablas solo en español cada semana.
Evalúa de 0% a 100%, qué porcentaje de tu tiempo hablas solo en español cada día.

**Language stability**
¿Es tu nivel de español estable? Sí/No
¿Aun estás mejorando tu nivel de español? Sí/No
¿Estás perdiendo habilidades en español? Sí/No

**Language history**
¿Cuántos años tenías cuando aprendiste español?
¿Cómo aprendiste español?
¿Dónde aprendiste español?
¿Con quién aprendiste español?
Function of languages

¿En qué momentos de tu vida cotidiana hablas en español?

¿Dónde hablas español?

¿Con quién hablas español?
## PARTICIPANT INFORMATION FORM

**PAGE 1**

**DR. CONOR T. M\textsuperscript{i}LENNAN, ASSOCIATE PROFESSOR AND DIRECTOR**  
**LANGUAGE RESEARCH LABORATORY**  
**CLEVELAND STATE UNIVERSITY: DEPARTMENT OF PSYCHOLOGY**  
**CHESTER BUILDING 249-251**  
**(216) 687-3834**

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### FOR LRL USE:

- Room #: ____________
- Participant #: ____________
- _____ (credits) OR $__________
- Experiment #: ____________
- Date #: ____________
- Experimenter: ____________

---

**Please fill in the following information:**

**Name:** ____________________________________________ *

**Address:** ____________________________________________

**E-mail address(es):** ____________________________________________

**Telephone Number:** ____________  
**Cell Phone Number:** ____________

**Date of Birth:** ____________  
**Place of birth (City):** ____________

**Gender:** ____________  
**Major:** ____________________________________________

**Place of Longest Residence (City):** ____________________________________________

**First language spoken:** ____________________________________________

**Are you (circle one):** right-handed  
left-handed  
ambidextrous

**What languages do you speak fluently?** ____________________________________________

**Would you like to be added to (or remain on) our “Paid Participants Database” so that we can notify you in the future of paid experiments for which you are eligible to participate?** ____________________________________________
Please note that your responses to the following questions will not be directly linked to your name. As with any part of your experience as a research participant in our study, please feel free to ask the experimenter if you have any questions. Thank you.

Have you ever had a hearing or speech disorder?

(circle one)  YES    NO

If yes, please explain: ____________________________________________

Have you ever had a visual or reading disorder (other than glasses/contacts)?

(circle one)  YES    NO

If yes, please explain: ____________________________________________

Have you ever been diagnosed with Attention Deficit Disorder (ADD) or Attention Deficit Hyperactivity Disorder (ADHD)?

(circle one)  YES    NO

If yes, please explain: ____________________________________________
PARTICIPANT CONSENT FORM: PERCEPTION OF WRITTEN LANGUAGE

Dr. Conor T. McLennan, Associate Professor and Director
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Dr. McLennan, Associate Professor and Sara Incera, Doctoral Student, both in the Psychology Department at Cleveland State University, are conducting a series of studies examining readers’ perception of written language.

There are two copies of this consent form. After signing them, please keep one copy for your records and return the other copy. Thank you in advance for your cooperation and support.

“I agree to participate in a perceptual experiment in which I will see words or pictures on the screen and/or hear spoken words and/or nonwords over headphones. I agree to respond to these sounds by pressing a response button, repeating the word aloud into a microphone, or clicking on a location on the computer screen. I furthermore agree to the recording of my voice for acoustic analysis if the researcher explicitly informs me that my voice is being recorded. I also understand that I may be asked to participate in a memory span test and/or a test of processing speed. I understand that confidentiality of my identity will be maintained at all times.

I understand that the procedures to be followed in this experiment have been fully explained to me and that I may ask questions regarding the experiment at any time. I understand the approximate time commitment involved and that I will receive _____ credit(s) for my participation. I am also aware that I may refuse to continue the experiment at any time and that I will be excused without loss of credit.

I understand that participation in this experiment involves no known risks beyond those associated with daily living.

I understand that the purpose of this research is to add knowledge to the field of spoken word recognition. I understand that although there may be several indirect benefits of this study, its direct benefit is adding to the current body of knowledge on human perception.

I, the undersigned, am 18 years or older and have read and understood this consent form and hereby agree to give my consent to voluntarily participate in this experiment.”

I understand that if I have any questions about my rights as a research participant, I may contact the Cleveland State University Institutional Review Board at (216) 687-3630.”

_________________________   ______________________
Signature of Participant    Date
_________________________
Name of Participant (PLEASE PRINT)
_________________________   ______________________
Signature of Researcher    Date
You can further help us by providing answers to the following questions. There are no right or wrong answers. We are simply interested in your experience in the experiment that you have just participated in. If you have any questions, please ask the experimenter.

1. What do you think was the purpose of this experiment?

2. Did you have any problems hearing (and/or seeing) or understanding the words and/or nonwords you were presented?

3. Do you have any general comments or observations about the experiment?

4. Your gender is (circle one): Male Female

5. Your ethnic background is (circle one): Hispanic or Latino Not Hispanic or Latino

6. Your racial background is (circle one):
   - American Indian/Alaska Native
   - Native Hawaiian or Other Pacific Islander
   - White
   - Unknown
   - Asian
   - Black or African American
   - More than One Race
Thank you for your participation in this experiment today. In the Language Research Laboratory, we are interested in discovering how people understand spoken language. Specifically, we are trying to determine how people are able to recognize spoken words so rapidly and efficiently. You know tens of thousands of words, yet you can recognize even a very uncommon word without difficulty within a fraction of a second. We are interested in discovering the cues that you may use and the steps that your mind goes through in order to accomplish this task. The experiment you participated in today will lead us to a better understanding of these processes.

Thanks again for your participation in this experiment. If you have friends participating in experiments in this laboratory, please keep the purpose of this experiment confidential in case we ask them to help us out. If you have any further questions about this experiment, please feel free to ask. You may also contact the Language Research Laboratory at (216) 687-3834 if you have questions later that you wish to have answered.

If you have any questions about your rights as a research participant, you are encouraged to contact the Cleveland State University Institutional Review Board at (216) 687-3630. If you are interested in reading more about some of these issues, see the references given below.
