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Mouse-Tracking Reveals When the Stroop Effect Happens.

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Mouse-Tracking Reveals When the Stroop Effect Happens

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Abstract

We examined the continuous dynamics of the Stroop task using mouse-tracking. Participants moved the computer mouse to indicate the color of words presented on the computer screen in both congruent (blue in blue font) and incongruent (blue in yellow font) conditions. Mouse-tracking data revealed significant differences in reaction times, spatial attraction, and velocity. In the Stroop effect, word reading and color processing influenced performance, but they did so differently: Word reading influenced the early part of the mouse trajectory, but color processing influenced later parts. The data provide important new information about the real time processing dynamics underlying the effect.

The main purpose of our study is to examine the continuous dynamics of the Stroop effect. Stroop's (1935) article is one of the most influential studies in experimental psychology, currently cited over 7,500 times (Google Scholar). The Stroop task has become a standard measure of attention, yet the effect itself is not fully understood (MacLeod, 1991). Recently, the dynamic mouse-tracking paradigm (Spivey, Grosjean, & Knoblich, 2005) has been developed, proposing that hand movements reveal cognitive processes during psychological tasks. Freeman and Ambady (2010) introduced MouseTracker, software designed to examine real time processing. Importantly, mouse-tracking allows researchers to examine mouse trajectories during online competition between two response options (Figure 1). MouseTracker provides the temporal resolution necessary for examining the perceptual-cognitive processes involved during word recognition and attention (Freeman & Ambady, 2010). The logic is such that online measures (spatial attraction and velocity) of movements of the hand reveal the time course of mental processes.

Lindsay and Jacoby (1994) argued that lacking a factor-pure control, interference and facilitation could not be measured accurately. In mouse-tracking, the lack of response (no horizontal movements, only vertical movements) is a factor-pure baseline, while movements toward the correct response represent facilitation, and movements toward the incorrect response represent interference. Thus, mouse-tracking data distinguish interference from facilitation, providing new insights into the continuous dynamics of the Stroop effect.

A complete understanding of the Stroop effect had been limited by the use of end point measures (RT and accuracy). Using MouseTracker, we were able to examine online measures, which made it possible for us to 'walk' through the trial and discover characteristics of processing over time (Figure 1). We made the following predictions: (1) Reaction Times (RTs) will be faster for congruent trials than incongruent trials. (2) Spatial attraction towards the incorrect response will be smaller for congruent trials than incongruent trials. (3) Velocity will be greater for congruent trials than incongruent trials.

Method

MouseTracker measures were used during the performance of the classic Stroop color-naming task (Stroop, 1935). Following Klein (1964), four color words (BLUE, GREEN, RED, YELLOW) were presented in the middle of the screen in all four colors. Ten participants were instructed to indicate the color of each stimulus by moving the mouse from the bottom center to the responses (top right or left). Clicking START triggered the stimulus to appear in both the congruent (the word blue in blue font) and incongruent (the word blue in yellow font) conditions. Practice trials (XXXX in all colors) served as the control. Data were collected every 13-16ms. All responses were remapped 90 degrees to the right (Freeman & Ambady, 2010); therefore, correct responses are always on the right and incorrect responses on the left when presenting the results (Figure 1). Within participant t-tests were performed for the overall measures (RTs and area under the curve). Online measures (x-coordinate and velocity) were analyzed using a 2 X 2 within-participants analysis of variance with condition (congruent, incongruent) and time (bin1, bin2) as repeated measures.

Results

Data screening and preparation. There were a total of 64 target trials, half congruent, for a grand total of 640 trajectories across participants. Consistent with Miles, Betka, Pendry, and Macrae (2010), errors and trials with RTs greater than 4,000ms were discarded. Trials with an initiation time greater than 500ms were also discarded. Additionally, following Freeman and Ambady (2011), aberrant responses (erratic, non-interpretable trajectories looping leftward and rightward) were also discarded. Overall, 91.25% of the trials were included in the analyses. These deletions are standard in MT data; nevertheless, we found the same patterns of results without the deletions. We report 95% confidence intervals (CIs) throughout.

Movements were initiated around 160ms in both conditions ($t = 0.29$, $p = .78$). First, our results replicated the traditional finding of faster RTs in the congruent condition than in the incongruent condition, $t(9) = 7.032$, $p < .001$, $d = 0.877$. Second, according with hypothesis 2, spatial attraction towards the incorrect response was smaller in the congruent condition than in the incongruent condition (Figure 2). More specifically, area under the curve was smaller in the congruent condition, $t(9) = 7.154$, $p < .001$, $d = 2.473$. Moreover, in the x-coordinate data, the interaction between time (1: 250-350ms, 2: 350-450ms) and condition was significant, $F = 5.66$, $p = .04$). In the first bin (250-350ms), there were no differences between conditions; in the second bin (350-450ms), differences appeared, such that the congruent condition moved towards the correct response and the incongruent condition moved towards the incorrect response. Third, we were able to determine that the Stroop effect impacts velocity over the x-coordinate. In particular, congruent trials sped up more than incongruent trials, consistent with hypothesis 3 (Figure 2). The interaction between time (1: 350-800ms, 2: 800-1250ms) and condition was significant, $F = 11.56$, $p = .008$. In the first bin (350-800ms), velocity was greater in the congruent condition; nevertheless, in the second bin (800-1250ms), the pattern changed and velocity was greater in the incongruent condition.

Discussion

The mouse-tracking measures supplied rich trajectory data that revealed robust and significant differences in RTs, spatial attraction, and velocity. First, there were no differences in spatial attraction until around 350ms, the point at which we argue word reading occurred. Participants moved toward the correct response on congruent trials, toward the incorrect response on incongruent trials, and remained vertical on control trials (Figure 1). Second, participants moved toward the incorrect response on incongruent trials until color processing occurred (around 800ms, CI 95%: 674ms-983ms). Velocity data support this argument; congruent trials sped up while incongruent trials slowed down due to interference (Figure 2). These findings support the idea that word-related information (i.e., reading) is processed earlier than the color. Overall, we have evidence that 1) word reading and color processing both influence performance in a Stroop task, and 2) they do so at different times. Word reading influenced the early part of the mouse trajectory, and color processing influenced later parts of the mouse movement. To our knowledge, this is the first experiment that used the mouse-tracking paradigm to determine precisely when word reading and color processing occur.

One limitation of the current experiment is that the generality of the time-course differences is unknown. The time-course effects may differ with different stimuli, exposure rates, or a different form of interference. Nevertheless, we believe the order of the processes (first word reading, second color processing) is likely to remain stable. Future directions will directly examine the contribution of interference and facilitation processes, as well as variations of the Stroop task with different populations and different stimuli.

In conclusion, despite over 75 years of research using the Stroop task, these data provide important new information about the real time processing dynamics underlying the effect, revealing the order in which word reading and color processing occur. These results add to our knowledge of the Stroop effect, and to our knowledge of how mouse-tracking could be used to provide a deeper understanding of the time-course of cognitive processes. We agree with MacLeod (1991) that the Stroop effect will continue to challenge research psychologists, but we hope the empirical findings and theoretical implications of the current study contribute to the progress he predicted in the Stroop literature in the new millennium.

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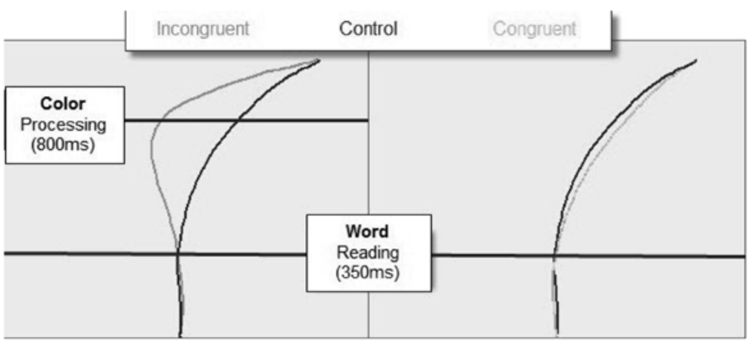

Figure 1. Mouse-tracking data for Incongruent, Control and Congruent conditions.

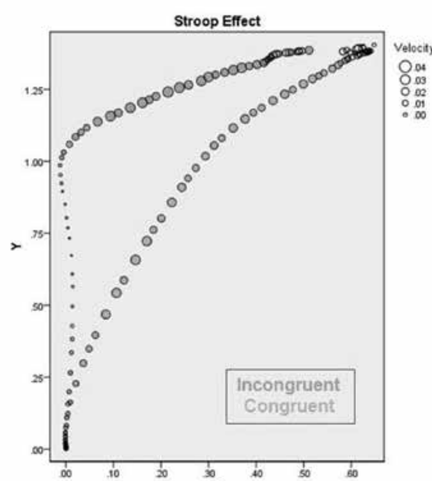

Figure 2. Online Velocity for Incongruent and Congruent conditions.

About the Author

Sara Incera, MS is a first year doctoral student in the Language Research Laboratory in the Psychology Department at Cleveland State University. Before moving to the USA, she gained valuable research experiences at University College Cork, in Ireland and the University of Salamanca, in Spain. She is also a licensed Spanish teacher and has worked in multicultural and bilingual settings. Her research interests include: language development, bilingualism, biliteracy, spoken word recognition, and examining how these processes may differ between younger and older adults. She is currently conducting research using the innovative software MouseTracker.

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