THE DEVELOPMENT OF ATTENTIONAL SKILL IN A RAPID SERIAL VISUAL PRESENTATION TASK: EFFECTS OF EXTENDED PRACTICE ON THE 'ATTENTIONAL BLINK'

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ABSTRACT

The selection of information through visual attention can be based on the time course of events as well as on the spatial location where information is presented. The *attentional blink* (*AB*) phenomenon reflects a limitation in selecting information based on time. This phenomenon is observed with a *rapid serial visual presentation* (*RSVP*) where the ability to accurately identify a *second target* (*T2*) is reduced when it follows 200 – 500 ms after the *first target* (*T1*). The goal of this study was to examine whether this deficit in identifying objects in time would be reduced through practice. This question was addressed by having young adults practice an RSVP task one hour a day for three consecutive days. The major result was that the magnitude and duration of the AB deficit and the proportion of errors in reporting the order of the two targets decreased substantially with practice. These results support theories of AB which assume the phenomenon is an outcome of cognitive control processes that are malleable. The results are not congruent with theories of AB based on fixed capacity limitations.

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CHAPTER 1

INTRODUCTION

A vast amount of information is presented to the senses at any given moment. Because our cognitive architecture is not capable of fully processing all the information presented to it at a given point in time, the ability to focus our mental resources on a restricted set of information relevant to current goals is crucial for functioning adaptively. Attention is the process which enables organisms to temporarily select a relevant subset of information for higher levels of processing. Although the manner in which attention is deployed in space has been studied extensively, the processes underlying deployment of attention in time are still not well understood. This study examined the role of practice in learning to direct attention toward stimuli that are presented at points in time. Specifically, I focused on a phenomenon known as *attentional blink* (*AB*), in which the second of two target stimuli which are presented in rapid succession often cannot be reported accurately. This represents a failure of attentional selection.

The deployment of attention may be determined by factors in the environment. A blinking red light or a car suddenly emerging into an intersection are examples of stimuli which are perceptually salient (Theeuwes, 1991). Attention to these types of stimuli is referred to as *exogenous attention*. However, the control of attention may also be *endogenous*—that is, directed by the moment-to-moment goals of the individual. Endogenous attention may be deployed in two dimensions—spatial and temporal—the *where* and the *when* of attentional fixation. In a pioneering study on spatial endogenous attention, Posner, Snyder, and Davidson (1980) demonstrated that a visual cue preceding a target in the same location enables more rapid detection of the target. This indicates that the processing of visual stimuli is enhanced by increased dedication of attentional resources to a spatial region.

It has also been demonstrated that attending to points in time enhances stimulus processing. Initial studies of the time course of attention focused on brief temporal intervals during which visual processing was suppressed for a given target (Broadbent & Broadbent, 1987). Later research clarified the AB phenomenon through the extensive use of the *rapid serial visual presentation* (RSVP) paradigm. In this task, targets, such as letters, and distractors, such as numerals, are presented one after another approximately at the rate of 10 items per second. In a representative RSVP task, two target stimuli, target one (*T1*) and target two (*T2*), are presented to the participant separated by a variable number of distractors. The number of positions by which T2 follows T1 in the stimuli stream is referred to as the *lag*.

In many variants of the RSVP paradigm, the participant is tasked with identifying both targets. The finding which has defined AB is the curvilinear pattern seen when accuracy for T2 is plotted as a function of time elapsed between the two targets. Specifically, when T2 is presented within 100 ms of T1, then it is reported accurately on approximately 75% of trials (Chun & Potter, 1995). This part of the phenomenon is referred to as ‘lag-1 sparing’. However, when T2 is presented 200 ms after T1 the accuracy of report drops to 35%. It is not until 500 ms after T1 that the accuracy rate for reporting T2 again reaches a level equivalent to that seen at 100 ms. This often replicated finding that attention is initially high, drops sharply, then gradually recovers led to the analogy of a “blink” in attention (Raymond, Shapiro, & Arnell, 1992).

Some early research into this phenomenon was designed to assess the level of processing at which this blink occurred. Researchers using words as targets have demonstrated that targets which are presented during the blink interval and not reported accurately still exert a semantic priming effect (Maki, Frigen, & Paulson, 1997). This finding argues persuasively that AB is not caused by an inability to perceive T2. Rather, these targets are perceived and processed to at least the point at which semantic information is extracted. This finding is congruent with the interpretation that the processing failure which leads to the AB occurs relatively late in the chain of events at the point at which identified targets are encoded into working memory (*WM*).

Although the basic phenomenon of AB has been extensively investigated, the role of practice and automaticity on AB has not been explored systematically. The goal of this study was to address this issue by testing predictions derived from several theories of AB. One set of theories for understanding the AB phenomenon relies heavily on the limited capacity of working memory. These theories dictate that the inability to report a target when it closely follows another target occurs due to the limitations of an attentional resource which is needed for the encoding of a target into working memory. This resource is equally necessary for both targets. When T2 is presented within the 200-500 ms interval after T1, the resource is often still being used by T1's encoding process and is unavailable to begin the process for T2. An integral part of this theory is that when this second target is not encoded into WM in a timely manner the memory trace is subject to decay, resulting in AB (Chun & Potter, 1995).

In linking AB directly to working memory, the capacity-limited theories seek to account for the phenomenon as a consequence of the structural limitations of working memory in terms of capacity and processing speed. A potential strength of this theoretical viewpoint is that in addition to accounting for the basic phenomena associated with AB, it could also account for individual differences in magnitude of AB. Although the AB is a robust phenomenon, research has pointed to differences in blink magnitude. Perhaps most surprisingly, some individuals seem to exhibit no AB at all. One research team has found that 7.7% of the participants in their AB studies exhibit very little to no AB (Martens, Munneke, Smid, & Johnson, 2006).

Differences in blink magnitude between young adults and older adults may correspond to changes in WM. Lahar, Isaak, and McArthur (2001) report greater AB magnitude among healthy older adults when compared to a college-aged control group. In research involving the same general age categories, Van der Linden, Brédart, and Beerten (1994) found evidence for an age-related decrease in WM update speed. However, research has demonstrated no clear correlation between an individual's AB magnitude and standard measures of WM capacity (Martens & Johnson, 2009). Thus, it remains unclear whether age-related changes in WM directly influence AB or merely follow a similar developmental trajectory.

A second set of theories regarding AB focuses on processes which are more malleable and may be responsive to demands of the individual. A finding by Di Lollo, Kawahara, Shahab Ghorashi, and Enns (2005) challenged the idea that AB is the result of the limited capacity of WM. This study used the *whole report* technique and demonstrated that when three targets are presented consecutively, without intervening distractors, participants are capable of accurately reporting all three targets— in essence, a "spreading" of the lag-1 sparing effect. In this case, the ability to report a third target (*T3*) is especially important due to the fact that in a typical RSVP task, the stimulus displayed 200 ms after T1 would fall within the AB interval and be the least accurately reported. This ability seems to indicate that while the capacity of WM may be limited, this limitation is not so severe as to prevent the encoding of more than one target within 200 – 500 ms.

To account for this phenomenon, AB theories emerged which explain the phenomenon as the result of a conflict between the component processes involved in the task rather than from a limited WM or attentional capacity (Dux & Marois, 2009). These *cognitive control theories* collectively propose that AB arises out of an error in the scheduling of two processes— the identification of targets and encoding of targets to WM. *Temporary loss of control* (*TLC)* is a prominent cognitive control theory proposed by Di Lollo et al. (2005) in which AB is seen as a failure in target identification rather than WM encoding. Identification is dependent on a template which is optimally configured for targets; the intrusion of a distractor causes this template to become temporarily deconfigured. AB results when T2 is presented before the template can become reconfigured to process targets. In TLC theory, both lag-1 sparing and the spreading the sparing effect are accounted for by the fact that the template has not yet been deconfigured by the presentation of a distractor.

In the TLC model, extensive practice with the task might allow for the development of a more finely tuned template. This could be accomplished by the incorporation of parameters other than simple target/distractor status. In a task as patterned as a typical RSVP task, temporal regularities would be a likely candidate for an additional parameter in this more elaborate filter. At high levels of practice the contributions to the overall filter strength made by this additional parameter could outweigh the contributions made by target/distractor status. Thus it would be expected that a reduction of AB would be seen with practice of a temporally predictable task.

TLC theory posits that AB results from too little control. In contrast, another cognitive control theory, the *threaded cognition model*, asserts that AB is a consequence of too much control (Taatgen, Juvina, Schipper, Borst, & Martens, 2009). In essence this model proposes a system in which the capacity of WM is adequate to encode all targets. However, the two component tasks involved in the RSVP, identifying and encoding, are subject to a processing rule which privileges the encoding of already identified targets over the detection of new targets. The effect of this rule, at the early lags of the RSVP task, is to ensure encoding of T1 at the cost of failing to identify T2, resulting in AB. The threaded cognition model asserts that because capacity is adequate both this processing rule and the AB it causes are unnecessary. Therefore, AB could be reduced or even eliminated, at no cost, by suspending an unneeded rule. A situation which lessens the emphasis on encoding T1 should lead to a suspension of the rule privileging this process. Indeed, several studies which deemphasized T1 encoding through the addition of a concurrent task to the standard RSVP design have demonstrated reduced AB (Olivers & Nieuwenhuis, 2006; Taatgen et al., 2009).

The threaded cognition model is of particular interest with regard to reduction of AB due to practice. Rather than requiring an addition to the theory, threaded cognition requires only that practice enable the suspension of an unnecessary rule which has a detrimental effect on task performance. In further support of their position that this rule privileging encoding is unnecessary, Taatgen et al. (2009) consider the empirical evidence which demonstrates that some individuals exhibit little or no AB (Martens et al., 2006). According to the threaded cognition model these individuals have already suspended the unnecessary rule. If this is the case, then ‘non-blinkers’ may actually be fast learners and with practice ‘blinkers’ may also come to suspend the rule in order to more accurately perform the task. Indeed, in their presentation of the threaded cognition model, Taatgen et al. (2009) found an effect of practice within a single session when comparing first and second blocks. Their research design did not allow for an investigation of the effects of extensive practice across multiple blocks or sessions.

A third cognitive control theory is the *boost and bounce* model proposed by Olivers and Meeter (2008), which proposes that admission to WM is made through an attentional gating system. This gate is a top-down mechanism which, like a filter, accepts or rejects stimuli depending upon whether they are targets or distractors according to the requirements of the task. The function of the gate is enhanced by feedback loops from the sensory neurons processing the stimuli. Neurons which process targets send an excitatory signal to the gate—a boost which increases the chances the stimulus will pass through the gate into WM. Neurons processing distractors transmit an inhibitory signal—a bounce which reduces their chance of passing the gate. However, because of a slight delay in this system, when stimuli are presented at the rate used in RSVP the boost or bounce generated by each stimulus also affects the following stimulus. In effect, targets open the gate for the next stimulus, while distractors increase the likelihood that it is closed. The boost and bounce model explains AB as an interaction between the boost generated by T1 and the bounce generated by a distractor occurring in Lag-1. To prevent the boost generated by T1 from enabling the distractor to enter WM, a violation of the rules configuring the gate, the bounce signal generated by the Lag-2 distractor is exceptionally strong. This strong bounce signal prevents a distractor from entering the gate. However, its lingering effect often overwhelms T2 when it occurs at short lags, resulting in AB.

In a previous study Olivers and Niewenhuis (2006) demonstrated that positive affect, instruction, and increased task load all led to reduced AB. Within the framework of the boost and bounce model these factors were all considered to indicate less focused concentration on the task and to “invoke a more distributed attentional state” (Olivers & Meeter, 2008, p. 856). According to the terms of this model, reduced focus on the task results in lower AB magnitude because both boost and bounce signals are weaker. Therefore the interaction between the two is also lessened.

Although they propose different mechanisms, both the threaded cognition and boost and bounce models can account for lower AB magnitude when focus on the RSVP task is reduced.

Although previous research points to considerable individual differences in AB profile, to date the question of changes in AB magnitude *within* individuals has not been adequately addressed. According to capacity-limited theories the potential for change would be expected to be limited to long-term changes taking place over the life-span. The cognitive control theories, as outlined above, allow for alteration of control processes by the individual. Therefore, predictions made from cognitive control theories do allow for short-term change, including AB reduction due to the effects of practice.

There are several studies of AB reduction which have used within-participants methodology. For the most part, this research was not designed specifically to answer questions related to RSVP practice. Instead, the researchers examined other types of training hypothesized to affect the temporal dimension of selective attention, using RSVP only as a means to test for these changes. In a study which compared a convenience sample of experienced action video game players with non-videogame players, Green and Bavelier (2003) found AB magnitudes among gamers which were significantly smaller than those found in non-gamers. In a subsequent study the researchers assigned participants with limited previous gaming experience to either a control group or an experimental group that trained with an action video game one hour per day. After ten days of training, participants in the experimental group were found to recover from AB more quickly. Green and Bavelier (2003) broadly attribute these findings to changes in attentional processing for visual stimuli created by the challenging visual environment inherent to the action video game.

Another study which revealed reduced AB within individuals was focused on the effects of meditation. Slagter et al. (2007) conducted AB research with participants before and after a three month retreat involving intensive training in Vipassana meditation. This form of meditation, which involves mindfulness of breathing, was hypothesized to lead to an increase in the ability to attend to regularly occurring stimuli. Using the RSVP task, all sixteen participants in the experimental group showed significant decreases in AB magnitude between sessions conducted before and after the meditation retreat. It is worth noting that some participants from the control group, who received minimal meditation training, also showed a significant decrease in blink magnitude. Slagter et al. (2007) concluded that AB results from the dedication of too much attentional resource to T1, not leaving enough to successfully encode T2 into WM. They suggest that intensive meditation training enabled their participants to redistribute attentional resources more evenly between targets. Lending support to this explanation were EEG results showing a reduced P3b component elicited by T1 in those participants who also showed a reduced AB magnitude (Slagter et al., 2007). Previous neuroelectric research has established a connection between the presence of AB and the presence of the P3 component for the first target (Vogel & Luck, 2002).

In each of the studies cited above the two sessions of RSVP training necessary to complete the study were treated as incidental. Although this research evidences that it is possible for individuals to reduce AB over time, they do so by testing the effects of applied skills rather than practice with the RSVP task unencumbered by the effects of other types of training. Research of the latter type has been limited in quantity and scope. Although Taatgen et al. (2009) report reduced AB between the first two blocks of a single session; they did not assess the potential effects of further practice. In a recent study, Nakatani, Baijal, and Van Leeuwen

(2012) report EEG and behavioral results indicating a modest reduction of AB between two sessions of RSVP training on separate days. However, this research did not require each participant to observe the same interval between practice sessions and allowed an average of five days between sessions. These choices allowed Nakatani et al. (2012) to craft a strenuous test of the effects of practice, but reduced the descriptiveness of their behavioral results. In addition, the researchers do not report results for the entire AB curve, choosing to focus on lag-1, lag-3, and lag-7. In general AB research these lags are often considered representative of the AB curve, however the study of practice effects benefits from a more detailed level of analysis.

While the results from previous research in this area demonstrate that practice with temporal attention tasks can reduce AB, the research reported here expands on these findings. The present study represents a merging of AB research with skill learning research. In principal, the rapid deployment of attention in the temporal dimension is treated as a skill which may be improved with training. In specific terms, the primary hypothesis being tested here is that extended practice with the RSVP task leads to a reduction of AB greater than that suggested by previous studies.

The current study investigated this hypothesis in several ways. First, this study allowed for the reproduction of prior results showing that relatively modest amounts of practice can lead to a significant reduction of AB within a single session. Second, through the use of multiple sessions on consecutive days, this study was specifically designed to test the limits by which practice can reduce AB. The amount of practice involved in this study, as well as its distribution between three sessions, was conceived to provide a strong manipulation. Third, an underlying goal of this research was to provide a description of practice-related changes across the entire AB curve, rather than simply focusing on lags representing the AB interval and the recovery period. To this end the AB curve was examined through the use of a component analysis method, grouping the six lags into four components, described in the Results section.

CHAPTER 2

METHOD

Participants

Twenty-three students from Indiana State University participated in this study. They were 18-25 years of age. Persons with a history of stroke, epilepsy or migraine were excluded from the study. In addition, all participants had normal or corrected-to-normal vision and were right-handed. Each participant received a payment of $45 after the third experimental session.

Apparatus

Stimuli were delivered and responses collected with a Sony Vaio L-series All-In-One PC with a built-in 1080p LED monitor and a 2.67 GHz processor. The RSVP task was conducted using a custom interface programmed with *E-Prime 2.0* software running in a Windows 7 environment. A chin rest was used to ensure that all participants maintained a viewing distance of 63 cm from the presentation monitor during experimental trials. To reduce distraction, the experiment took place in quiet and dimly lit laboratory with the monitor positioned to avoid glare.

Stimuli

This study used a version of the RSVP paradigm known as a *Letters-In-Numbers* task. As in other RSVP variants the stimuli were divided into two categories. In this study the *targets* consisted of the uppercase letters of the English alphabet. The *distractors* consisted of Arabic numerals. Several letters (I, O, U, and V) and numerals (0, 1, and 8) were excluded from the set of stimuli due to their featural similarity to another letter or numeral.

All stimuli were presented in 12-point Arial typeface. At the viewing distance of 63 cm the stimuli subtended .27° x .45° of the visual angle. Each stimulus object was presented in white on a black background in the center of the monitor.

Procedures

All participants gave informed consent, completed a demographic questionnaire and then performed an RSVP task. Participants were allowed five practice trials at the beginning of each session; these were not included for analysis.

Each participant trained with the RSVP task in three experimental sessions. These sessions were scheduled one per day on three consecutive days. To minimize the influence of potential time-of-day effects, the daily sessions took place within a fixed three hour window tailored for each participant.

Questionnaires

All participants gave informed consent, completed a demographic questionnaire and then performed an RSVP task. Participants were allowed five practice trials at the beginning of each session; these were not included for analysis.

Each participant trained with the RSVP task in three experimental sessions. These sessions were scheduled one per day on three consecutive days. To minimize the influence of potential time-of-day effects, the daily sessions took place within a fixed three hour window tailored for each participant.

RSVP task

Experimental trials were initiated by the participant, who pressed the *Enter* key to begin each trial. A central fixation cross was presented for 300 ms. Then, two targets and seven distractors were presented one at a time at a rate of 10 per second. The final stimulus was a pound symbol (#). Each trial concluded with an on-screen prompt requesting the participant to use the keyboard and enter the two letters in the order in which they appeared.

For each trial, the identities of the distractor and target stimuli were chosen using a pseudo-random design without replacement, such that each letter or numeral only appeared once within a trial. Also, the two target stimuli were required to be different and the distractor stimuli never occurred in direct numerical order for three or more distractors.

T1 always appeared as the second stimulus object in the RSVP stream. Relative to T1, T2 was presented in each lag from lag-1 to lag-6. Thus, T2 occupied an actual position in the stream varying from the third to the eighth position. For each trial the lag in which T2 appeared was chosen pseudo-randomly with the restriction that T2 occurred in each of the six lags once per six trial cycle.

Each research session consisted of five blocks. A block was composed of ten cycles of six trials each. The experiment was paced by the participant. Scheduled rests took place after the first and fourth blocks.

Participants were informed of the importance of completing all sessions at the beginning of the experiment. To ensure that they remained naïve to the hypothesis, participants were not fully debriefed until after their third session. In addition, participants received compensation for all three experimental sessions after completion of the third session.

To study the possible effects of any intentional strategies the participants' might have used to decrease their AB magnitude it was first necessary to determine whether participants were aware of these decreases. At the end of the third experimental session, each participant completed a questionnaire (see Appendix B) regarding their beliefs about their own performance. Specifically, participants were asked to record the percentage of trials which they believed they had answered correctly. This questionnaire included items pertaining to perceived accuracy for T1 individually and T2 individually; as well as for trials in which both T1 and T2 were perceived to have been answered correctly. Participants provided estimates for each of the three experimental sessions individually, as well an averaged score for all three sessions.

CHAPTER 3

RESULTS

Twenty-three participants completed the three required experimental sessions. Two participants were excluded due to a very low proportion of either correct T1 identification or correct T2 identification. One participant was excluded due to a very high proportion of correct T2 identification. The average age of the 20 participants (65% male) included for analysis was 21.7 years.

The following section first reports the overall performance for each target individually as well as for the two targets together. Secondly, I turn to the AB curve and report the results of the component analysis for each target. Third, I report the results from the questionnaire responses. To reduce the likelihood of Type 1 error, the reported results focused on the statistically significant contrasts rather than all possible main and interaction effects.

Overall Performance

I analyzed three measures to study overall task performance. The first measure was the proportion of trials in which T1 was identified correctly (*p*(T1)). The second measure was the proportion of trials in which T2 was identified correctly (*p*(T2)). The third measure corresponds to proportion of trials in which both T1 and T2 were correctly identified (*p*(T1&T2)).

Figure 2 plots each measure separately by block and by session. Separate 3 (Session) x 5 (Block) analyses of variance (ANOVAs) were conducted on each measure. These analyses show that performance increased with practice in each case, reflecting significant main effects for session and block, as described below. In addition, regression analyses of the learning curve are reported.

ANOVAs

p(T1) increased significantly between Session 1 and Session 2, $F(1,19) = 7.75$, $p < .05$. In the case of *p*(T2), performance increased steadily between all three sessions, *F*s > 24, *p*s < .01. *p*(T1&T2) improved between all three sessions *F*s > 13, *p*s < .05. Interestingly, for *p*(T2) and *p*(T1&T2), performance increased from Block 1 to Block 2 for all sessions, $F = 8.814$, $p < .01$ for *p*(T2) and $F = 8.737$, $p < .01$ for *p*(T1&T2). After this early within-session improvement there was a leveling of change until early in the next session.

Regression analyses.

To further explore the shape of the learning curve throughout all three sessions (15 blocks) of practice, I performed regression analyses on overall performance across all fifteen blocks. In these analyses the predictor variable was block number. The criterion variable was the value, averaged between all participants, for each measure. These analyses indicated that *p*(T1), *p*(T2), and *p*(T1&T2) were a linear function of block number. Specifically, $R^2 = .44$, $p < .01$ for *p*(T1), $R^2 = .88$, $p < .01$ for *p*(T2), and $R^2 = .86$, p < .01 for *p*(T1&T2). Power functions accounted for the data to a similar extent, $R^2 = .36$ for *p*(T1), $R^2 = .86$ for *p*(T2), and $R^2 = .84$ for *p*(T1&T2).

The results of analyses performed on block means, which average together trials from all six lags, pertain to overall performance on the RSVP task. Practice is demonstrated to have an effect at the session level on all three measures, and block-related effects on *p*(T2) and *p*(T1&T2). This is a first step in studying AB reduction. However, as a phenomenon AB is observed in the curvilinear shape of accuracy results when graphed by lag. Therefore, to examine AB reduction it is necessary to analyze the AB curve.

Identification of the Second Target Conditional on First Target Identification

Analyses in this section were performed on an additional measure, the proportion correct T2 identification for trials where T1 was correctly identified (p(T2|T1)). This measure was used to compute the magnitude of AB, which is defined as the difference in p(T2|T1) between the Lag-1 Sparing and Blink Interval components, described below.

In order to analyze the entirety of the AB curve I grouped the six lags into four components. The importance of the lag-1 sparing phenomenon dictated that Lag-1 should be treated as a separate component (*'Lag-1 Sparing'*). Accuracy during AB tasks is typically observed to be at its lowest during the 200 - 300 ms after T1, therefore Lag-2 and Lag-3 comprised the blink interval component (*'Blink Interval'*). Lag-4 is conceived as a separate component (*'Transitional'*) because AB is sometimes observed to extend to this lag, while at other times it does not. Theorists converge on 500 ms as the point by which recovery from AB is complete, therefore Lag-5 and Lag-6 made up the recovery component (*'Recovery'*).

Component Analyses

Figure 3 presents p(T2|T1) as a function of lag for each experimental session. I conducted a 4 (Component) x 3 (Session) x 5 (Block) ANOVA on p(T2|T1). There was a significant effect of Session between all three sessions Fs > 6, ps < .05. For p(T2|T1) the effect of Block was limited to the finding that Block 2 and all subsequent blocks were significantly higher than Block 1, Fs > 5, ps < .05. p(T2|T1) for Lag-1 Sparing was significantly greater than that for the Blink Interval, $F(1,19) = 21.762$, p < .01. p(T2|T1) for the Transitional and Recovery components were each significantly higher than that of the Blink Interval, Fs > 9 ps < .01. A significant Session x Component interaction effect indicated that the difference between Lag-1 Sparing and Blink Interval was smaller for Session 3 than for Session 2, $F(1,19) = 10.555$, $p < .01$.

To test for the presence of AB and the presence of recovery within each session, I conducted individual 5 (Block) x 4 (Component) ANOVAs with repeated contrasts. During Session 1, *p*(T2|T1) decreased significantly between Lag-1 Sparing and the Blink Interval, $F(1,19) = 20.364$, $p < .01$. However, *p*(T2|T1) for the Transitional component was not significantly greater than that of the Blink Interval, $F(1,19) = .679$, $p > .05$. A supplementary analysis with paired-samples *t*-test was conducted to compare *p*(T2|T1) for Blink Interval and Recovery. There was not a significant difference in the scores for Blink Interval ($M = .644$, $SE = .03$) and Recovery ($M = .669$, $SE = .03$) components; $t(19) = -1.067$, $p = .299$. During Session 2, *p*(T2|T1) decreased significantly between Lag-1 Sparing and Blink Interval, $F(1,19) = 24.291$, $p < .01$. In this Session *p*(T2|T1) increased significantly between Blink Interval and the Transitional component, $F(1,19) = 11.872$, $p < .01$. During Session 3, *p*(T2|T1) decreased significantly between Lag-1 Sparing and Blink Interval, $F(1,19) = 4.900$, $p < .05$. During Session 3, *p*(T2|T1) increased significantly between Blink Interval and the Transitional component, $F(1,19) = 6.869$, $p < .05$.

To explore the differences within AB curve components, I conducted individual 3 (Session) x 5 (Block) ANOVAs on each component. There were reliable Session-related increases in *p*(T2|T1) for several components. The Blink Interval showed significant increases between all three sessions, *F*s > 7, *p*s < .05. The Transitional component increased significantly between Session 1 and Session 2, $F(1,19) = 19.769$, $p < .01$. Finally, the Recovery component displayed a significant increase between each session, *F*s > 13, *p*s < .01.

The ANOVAs conducted on individual components also revealed one significant difference in p(T2|T1) which was related to Block. The Transitional component increased significantly between Block 1 (M = .706, SE = .039) and Block 2 (M = .770, SE = .034), $F(1,19) = 4.472$, $p < .05$.

The ANOVA conducted on Blink Interval resulted in two significant interaction effects. The comparison between Session 1 and Session 2 indicates that there was a significant difference in the amount of change between Blocks 2 and 3, $F(1,19) = 6.117$, $SE = .023$. In addition, when comparing Session 1 to Session 2, there was a significant difference in the change between Blocks 3 and 4, $F(1,19) = 5.857$, $SE = .026$.

Blink Duration

p(T2|T1) was used to examine blink duration, which is defined as the number of lags where p(T2|T1) is significantly lower than Lag-1 Sparing. For each session, a 5 (Block) x 6 (Lag) ANOVA was conducted. Here, the analysis involving Lag focused on the comparison between p(T2|T1) at Lag-1 and p(T2|T1) at each Lag from 2-6, using simple contrasts. The results of this analysis for Session 1 indicated that performance at all Lags 2-6 was significantly worse than at Lag-1, Fs > 6, ps < .05. During Session 2, Lag-4 and Lag-5 did not differ significantly from Lag-1, while Lag-2, Lag-3, and Lag-6 were significantly less accurate than Lag-1, Fs > 5, ps < .05. Within Session 3, only Lag-2 was significantly less accurate than Lag-1, $F(1,19) = 5.009$, $p < .05$.

Summarizing the results concerning identification of the second target conditional on first target identification, several things become clear. First, accurate identification increased between sessions for all components, save Lag-1 Sparing. Second, there were differences in the rate at which components increased. Third, the duration of AB was reduced with each session.

Identification of the First Target

For *p*(T2|T1) I reported that recovery was not apparent until Session 2 and continued to improve during Session 3. Also, *p*(T2|T1) components all increased across sessions, except for Lag-1 Sparing. To explore the possibility that these changes were reflected in T1 performance, I analyzed *p*(T1) in a way which corresponded to the analysis of *p*(T2|T1). Figure 4 plots *p*(T1) by lag of T2 presentation. In addition, I examine the proportion of total trials which resulted in reversal errors.

First, I conducted 4 (Component) x 3 (Session) x 5 (Block) ANOVA on *p*(T1). There was an effect of session, such that *p*(T1) for Session 2 was significantly higher than for Session 1, $F(1,19) = 6.379$, $p < .05$. An effect of component was discovered, indicating that *p*(T1) was significantly lower when T2 was presented during the Blink Interval than when T2 was presented at Lag-1 Sparing, $F(1,19) = 4.841$, $p < .05$.

Separate 5 (Block) x 4 (Component) ANOVAs with repeated contrasts performed for each Session reveal that *p*(T1) did not vary significantly by component of T2 presentation. The implications of this null result are explored in the Discussion.

Individual 3 (Session) x 5 (Block) ANOVAs performed on each AB curve component indicated several significant session-related increases in *p*(T1). Blink Interval shows a significant increase between Session 1 (M = .873, SE = .017) and Session 2 (M = .987, SE = .016), $F\ (1,19) = 4.535$, $p < .05$. In addition, Recovery displayed an increase between Session 1 (M = .864, SE = .018) and Session 2 (M = .893, SE = .015) which was significant, $F(1,19) = 7.903$, $p < .05$.

Two of the AB curve components showed a significant decrease in *p*(T1) related to block. Lag-1 Sparing decreased between Block 2 ($M = .932$, $SE = .014$) and Block 3 ($M = .900$, $SE =$

.022), $F(1,19) = 4.974$, $p < .05$. Additionally, when T2 was presented within the Blink Interval, *p*(T1) decreased significantly between Block 4 ($M = .911$, $SE = 0.18$) and Block 5 ($M = .867$, $SE = 0.19$), $F(1,19) = 8.025$, $p < .05$.

Scrutiny of the results for identifying T1 revealed that decreases in accuracy for *p*(T1) were rare. Second, the pattern of results for *p*(T1) did not indicate that increases for *p*(T2|T1) came at the expense of decreases to *p*(T1).

Reversal Errors

In order to closely examine the accuracy with which the targets were identified, I analyzed the proportion of total trials which were reversal errors, where the values of both targets are reported correctly but their order is reported incorrectly (*p*(Rev)). Figure 5 presents *p*(Rev) plotted by lag and session. I conducted a 3 (Session) x 5 (Block) x 6 (Lag) ANOVA which tests for effects of Lag and Session. There was a significant decrease in *p*(Rev) between each lag from Lag-1 to Lag-4, *F*s > 18, *p*s < .01. In addition, *p*(Rev) shows an effect of session, with the proportion of reversals reduced significantly between Session 2 ($M = .040$, $SE = .006$) and Session 3 ($M = .033$, $SE = .004$), $F(1,19) = 6.401$, $p < .05$. In a supplemental analysis of reversals only at Lag-1, a 3 (Session) x 5 (Block) ANOVA with polynomial contrasts displayed a significant linear effect of Session, $F(1,19) = 6.741$, $p < .05$.

Thus, reversal errors were substantially more common at Lag-1 than any other lag. Also, reversal errors at Lag-1 became significantly less frequent with practice.

Questionnaire Responses

Participants were requested to estimate the proportion of trials in which they responded correctly for each measure. A separate estimate was made for each session individually and for the average of the three. Based on the individual session estimates, I computed change scores as follows:

Estimated Change_j = (Estimated Accuracy_j – Estimated Accuracy_1)/Estimated Accuracy_1

Where *j* represents the session number from 2 to 3.

Table 1 presents the results of correlational analyses conducted between the estimated change scores and change scores computed from the actual proportion correct from the overall session averages. Separate analyses were conducted between each session for *p*(T1), *p*(T2), *p*(T1&T2). These tests revealed one significant correlation. For *p*(T1&T2), the participants' estimated change between Session 1 and Session 3 correlated significantly with their actual change between Session 1 and Session 3, $r(18) = .41$, $p < .05$.

Five participants reported playing video games on a regular basis (M = 14.20 hours per week, SE = .623). Two participants reported meditating regularly (three and four hours per week). A power analysis indicated that there was insufficient power to make comparisons between gamers and non-gamers or between meditators and non-meditators.

In summary, the results of this study indicated that practice enabled the participants to perform the RSVP task with increased accuracy. Through an analysis of all trials, regardless of lag of T2 presentation, it was demonstrated that there was an improvement in accuracy for all measures. In addition to this generalized increase in accuracy, an analysis, which involved separate tests for the individual lags of T2 presentation, showed that as a result of practice *p*(T2|T1) became more accurate during the specific lags which make up the blink interval. Furthermore, with each successive practice session there were fewer total lags in which p(T2|T1) was significantly less accurate than at Lag-1. Interestingly, there was also a decrease in the proportion of errors resulting from incorrectly reporting the order of the two targets, this was found at all lags of T2 presentation, including Lag-1. Lastly, for the measures *p*(T1), *p*(T2), and *p*(T1&T2), when comparing the actual change between sessions to the participants' estimated change between sessions, there was a significant correlation for *p*(T1&T2) between Session 1 and Session 3.

CHAPTER 4

DISCUSSION

The overarching goal of this study was to test the hypothesis that extensive amounts of practice with the RSVP task will lead to a reduction of attentional blink, potentially resulting in its elimination. The results reported here, while not amounting to the total elimination of AB, indicate that the magnitude and the duration of AB clearly decreased substantially over the course of three sessions, with the bulk of the within-session increase localized to the first two blocks. The linearity of the learning curve is suggestive of further improvements with additional practice.

The present study is consistent with a recent neurophysiological study of practice-related AB reduction (Nakatani et al., 2012). In this study participants completed two practice sessions, each a single block of 288 trials and separated by several days. Consistent with the results of the current study, the AB was reduced. However, their computation of AB magnitude relied upon comparisons between the blink lags and the recovery lags, rather than between the blink lags and lag 1 as in the current study. In that study, lag 1 sparing also increased proportionately with improvements at the Blink Lags. The cause of this discrepancy is unclear. In addition, the present study shows continuing improvement throughout the three practice sessions that spanned 900 trials. In addition, the current study showed that the duration of the blink was also reduced with practice. This finding is reminiscent of the reductions in blink duration found in Green and Bavelier (2003), which resulted from videogaming practice rather than RSVP practice.

The fact that performance on a dual-target RSVP task can improve with practice cannot be accounted for by capacity-limited theories of AB that attribute the blink to architectural limitations like working memory capacity. In contrast, the current findings support the family of theories that puts cognitive-control processes at the root of AB. The greater flexibility of these processes in explaining AB while accounting for phenomena such as whole report (Di Lollo et al., 2005) or AB reduction due to additional task load (Olivers & Niewenhuis, 2006) is consistent with the assumption that attentional processes underlying AB are adaptable. Different theories offer specific mechanisms that could be modified to support enhanced identification of the two targets.

In their TLC theory, Di Lollo et al. (2005) attribute AB to the use of a template to identify targets, which must be disabled when a distractor is presented. When a second target is then presented, the template must be reconfigured for identification of that target. Conceivably, within the terms of the TLC framework, practice might reduce AB by allowing T1 to be consolidated more rapidly, thus permitting reconfiguration of the target template early enough to identify T2. Preliminary research findings from an experiment using a visual search task indicate that WM encoding speed may be increased when participants are able to detect and learn statistical regularities within a set of stimuli (Rhee, Konkle, Brady & Alvarez, 2011). Over the course of 900 trials the *inter-stimulus intervals* (ISI) used in the RSVP task present a stable pattern of statistical regularities. In addition, in the current study T1 was presented at a fixed position as the second stimulus in the RSVP stream, contributing to the regularity inherent in the stimulus pattern. Therefore, further research is needed to explore the role of timing as a source of a type of statistical regularity that can be learned to improve WM encoding speed.

The cognitive control mechanism which Olivers and Meeter (2008) propose to account for AB is an attentional gate which controls admission to WM. The gate is configured to admit targets and block distractors. This theory specifies that the gate can be flexibly configured in order to accommodate different definitions of targets and distractors depending on the task at hand. However, this flexibility comes at the price of a slower gate. To offset this loss of speed, the gate's function is enhanced in two ways. Excitatory—boost—signals from sensory neurons processing targets, fling the gate open, whereas inhibitory—bounce—signals close it temporarily to potential distractors. According to this framework, the AB occurs because of an interaction between boost and bounce, resulting in an augmented bounce signal. Less focus placed on T1 would result in a lessened boost signal. In turn, the interaction between this boost signal and the bounce signal generated by the Lag-1 distractor would also be reduced. This would prevent the augmented bounce signal which causes AB. In this study, T1 was highly predictable because it was always presented as the second stimulus. Jones, Moynihan, and Puente (2002) have reported that practice with predictable stimulus presentation intervals enabled participants to improve perceptual processing. Therefore, the amount of focus necessary for reporting T1 would be reduced with increasing practice. The end result would be reduced AB.

Of the three cognitive-control process theories presented here, the threaded cognition model proposed by Taatgen et al. (2009) seems to require the fewest assumptions in order to account for practice-related AB reduction. Briefly, the threaded cognition model proposes that WM capacity is more than adequate to complete both the encoding and detection tasks. However, in order to privilege accurate encoding, a production rule is applied which would suspend further target detection until encoding of the first target is completed. Under the conditions of the RSVP task, at short lags, this may result in AB. Thus, the threaded cognition model could account for practice-related AB reduction by assuming that the rule was suspended with increasing frequency as practice progressed. The results of Taatgen et al. (2009) strongly suggest that such rule suspension is possible when the dual-target RSVP task is performed concurrently with a secondary task; AB was reduced under the increased demands of a dual task situation. Interestingly, and consistent with the results of the current study, Taatgen et al. (2009) also found a modest AB reduction for the control group who performed the RSVP task without a concurrent task, suggesting that practice itself might allow the rule to be relaxed.

The threaded cognition model does not specifically provide a mechanism by which practice relaxes the overexertion of control and thereby reduces AB. However, cognitive control is presumed to be responsive to the demands of endogenously specified goals such as those involved in accomplishing the RSVP task. To the extent that reduction of control would lead to enhanced RSVP performance, one might expect the suppression of a processing rule which was counterproductive to successfully completing the task.

A considerable amount of the scholarship regarding the cause of AB has focused on the idea that some attentional resource is in short supply. At their root, the capacity-limited theories propose that the short lags of the RSVP task regularly produce a demand which cannot be met. However, the weight of empirical evidence also suggests that there are abundant resources available to T1. Therefore, some theories of blink reduction have focused on redistribution of resources from T1 to T2 as a mechanism for AB reduction (Cavanagh & Alvarez, 2005). With respect to the effect of meditation on AB, Slagter et al. (2007) presented neurophysiological evidence for resource reallocation from T1 to T2 thought to be responsible for observed reductions in blink magnitude accompanying meditation. The current results showed that accuracy for T1 either increased or remained static. While it is difficult to ascertain from these results whether resources were reallocated in favor of T2, it is possible that identification for both targets required fewer and fewer resources with practice.

The finding that reversal errors decreased between sessions also has implications for AB research. Reversal errors are a standard phenomenon in AB research, they most commonly occur when T2 is presented in lag-1, as confirmed also in the present study. Consequently, several theories have attempted to account for them as a part of lag-1 sparing. In general, the reasoning behind this account is that because the two targets occur in such close temporal proximity, and without intervening distractors, they are simply encoded to WM together as one perceptual episode (Bowman & Wyble, 2007). In short, the reversal error occurs because order information is not maintained and the individual responds with a guess. The current result that reversal errors decreased with session implies that practice had enabled a more detailed encoding process with a greater emphasis on preserving fine-grained temporal distinctions.

Alternatively, some theories propose that reversal error does not result from an inability to maintain order information. Rather, they suggest that T2 is retrieved first because it was encoded first (Olivers, Hilkenmeier, & Scharlau, 2011; Wyble, Bowman, & Nieuwenstein, 2009). From the perspective of the boost and bounce model, when a second target occurs in lag-1 it benefits from a boost generated by first target. The sum of this boost and its own activation may allow the second target to race past the first into the attentional gate. Following this logic, the observation that practice leads to fewer such occurrences implies an increasingly sophisticated use of boost, which ensures that the order by which targets enter WM more accurately reproduces their actual order of presentation.

The cognitive control theories of AB assume that endogenous goals for attention play a meaningful role in the way specific attentional processes function. In addition, empirical studies have shown that increased task load, instruction, positive affect, and differential reward schemes lead to differences in AB (Della Libera & Chelazzi, 2006; Olivers & Niewenhuis, 2006). The speed of presentation used in the RSVP is believed to preclude effects due to consciously directed behaviors. However, it is possible that the large amount of practice changed the conscious goals in performing the RSVP task. To explore this possibility, I obtained participants' reports about their perceived performance in the RSVP task. The idea was that in the absence of explicit feedback a participant's ability to estimate his or her performance would be closely tied to the ability to improve performance through explicit strategies. Although most correlations did not achieve significance, the measure *p*(T1&T2) did show a significant correlation between the participants' estimated improvement from Session 1 to Session 3 and their actual improvement between these sessions. This indicated that participants had developed some ability to detect improvements in their own performance. Awareness of improved accuracy would be required in order for practice-related improvement to be the result of strategic deployment of attention. However, awareness does not necessarily imply that improvement resulted from the strategic deployment of attention. Explicit knowledge of improvement could arise despite that improvement resulting from implicit processes.

An important direction for future research concerns the specific factors which led to the AB reduction demonstrated here. One possibility is the temporal regularity of the ISIs between RSVP stimuli, which could have facilitated the categorization of targets and distractors. Interestingly, during the first session the AB curve lacked the distinct recovery that follows the AB typically found in most AB studies. However, such a recovery phase emerged by the second practice session. The current study contrasts with previous AB studies in that the current study always presented the first target as the second stimulus in the RSVP stream, whereas the position of T1 in an RSVP series has usually been varied in previous studies. It is possible that the opportunity to adjust to the RSVP rhythm prior to T1 presentation is important for recovery from AB. This is also a topic for future research.

In conclusion, the current study demonstrated that extensive practice in an RSVP task can result in the reduction of AB magnitude and duration beyond the boundaries established by previous research. This suggests that the deployment of attention to specific points in time is a skill that can be improved with a relatively small amount of training. A deficit in temporal attention which was previously believed to result from structural limits inherent to the cognitive system is likely an outcome of malleable control processes.

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Table 1. Results of Performance Questionnaire Correlation Analyses

Correlations Between Scores Representing Actual Change and Participants' Estimated Change for p(T1), p(T2) and p(T1&T2.

	Actual Change		
Estimated Change	Session 1 to 2	Session 2 to 3	Session 1 to 3
T1			
Session 1 to 2	-.13		
Session 2 to 3		.29	
Session 1 to 3			.05
T2			
Session 1 to 2	-.41		
Session 2 to 3		-.37	
Session 1 to 3			-.31
T1&T2			
Session 1 to 2	-.28		
Session 2 to 3		.24	
Session 1 to 3			.41*

Note. All tests are one-tailed. $n = 20$ for all measures. $*p < .05$

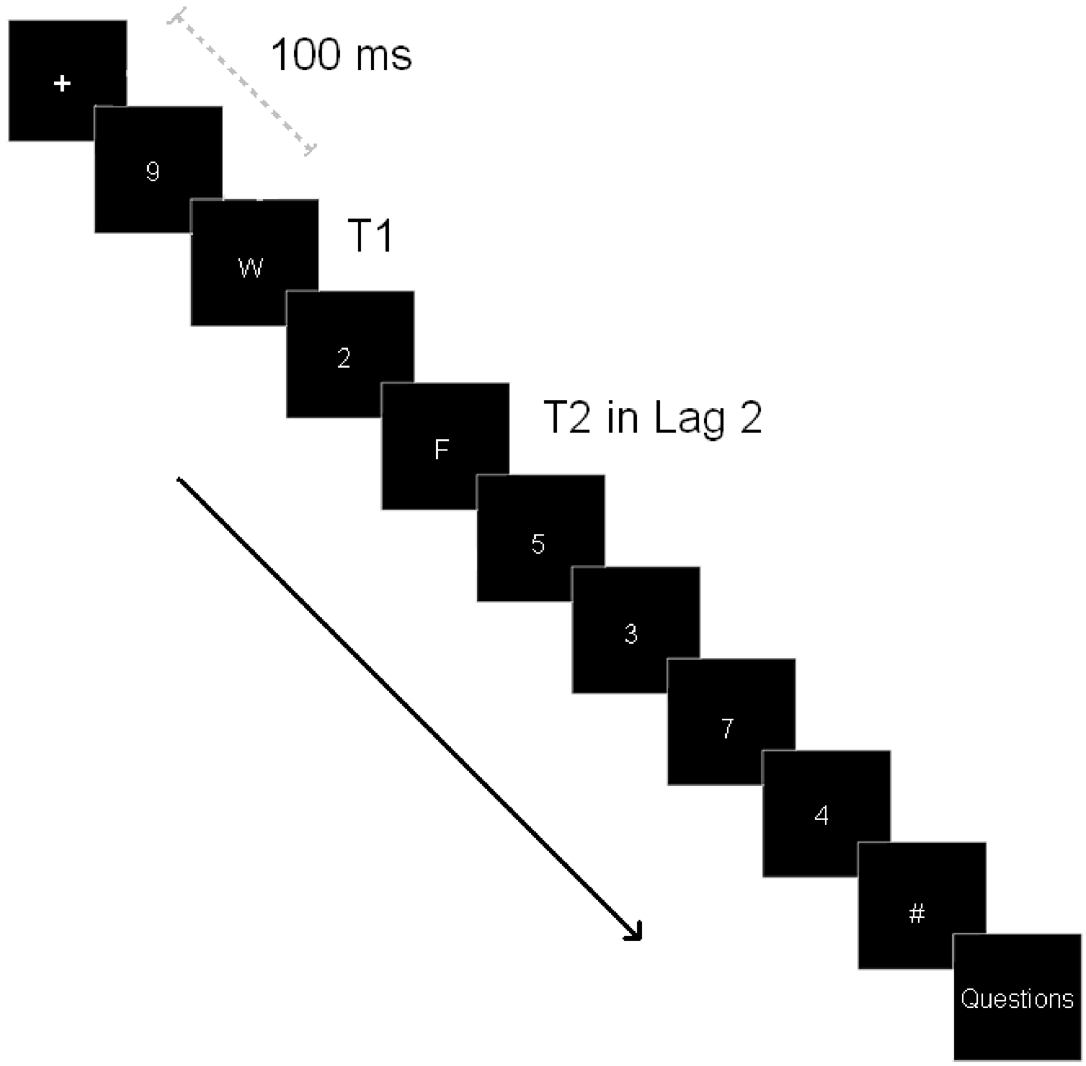

Figure 1. Diagram of a Sample RSVP Trial.

Diagram of a sample RSVP trial likely to result in attentional blink, showing targets, lag and temporal interval.

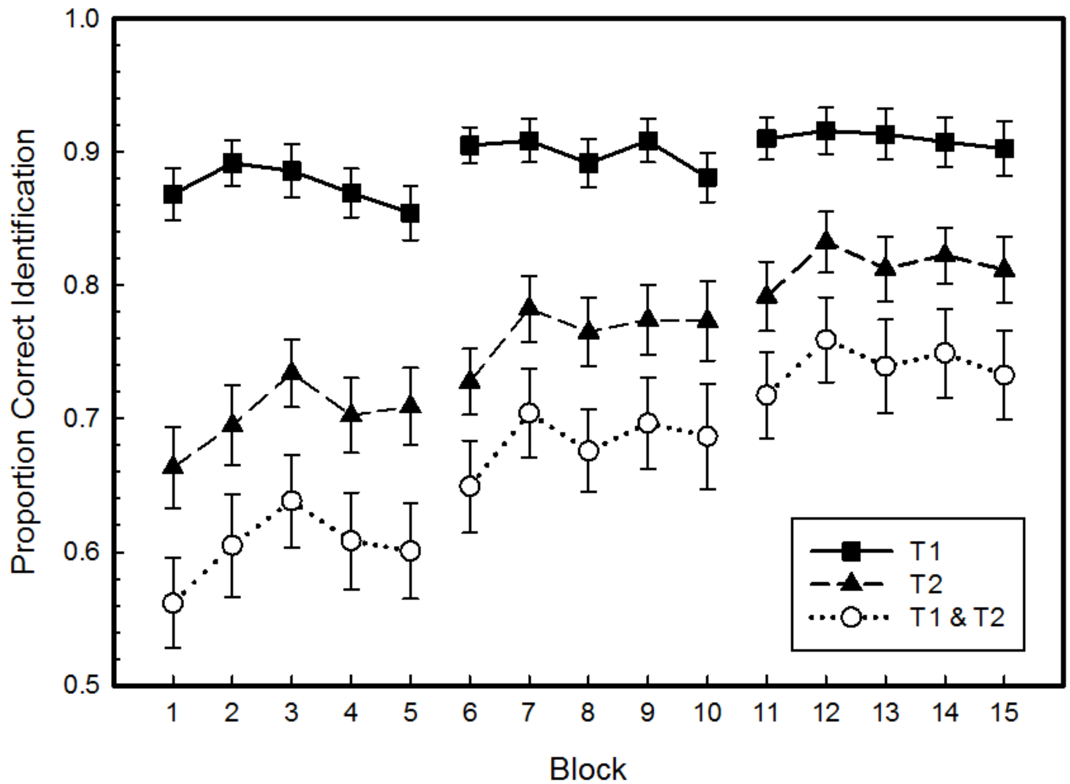

Figure 2. Results of Block Mean Analysis.

Block mean values for proportion correct for each measure. Block means include scores from all six lags. Blocks 1-5 took place during Session 1, Blocks 6-10 during Session 2, and Blocks 11-15 during Session 3. Error bars indicate standard error of the mean for each block value.

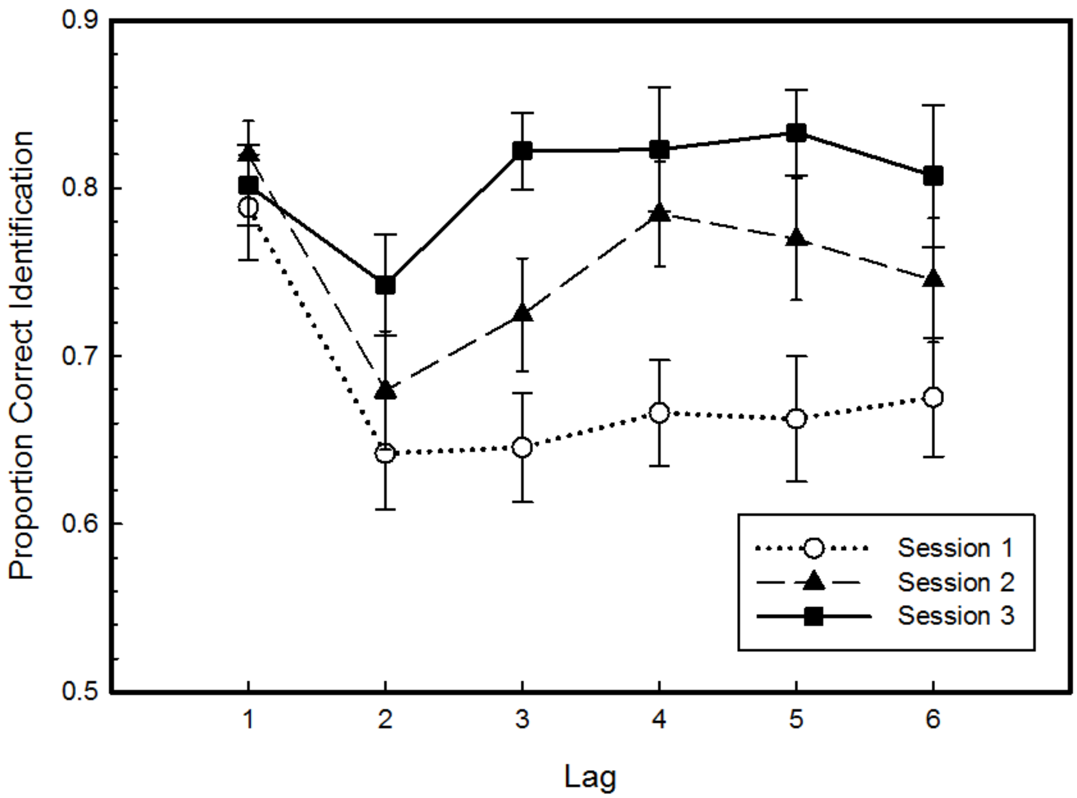

Figure 3. Results of T2|T1 Lag Analysis.

Proportion correct identification of T2 conditional on correct T1 identification plotted as a function of lag. Error bars indicate standard errors.

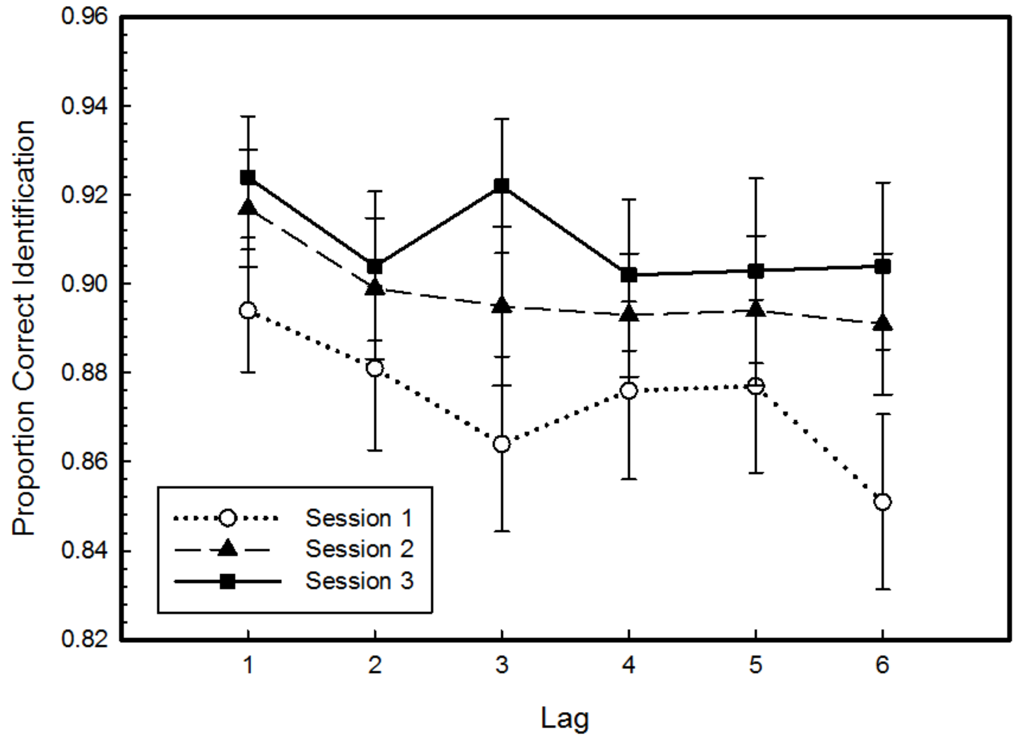

Figure 4. Results of T1 Lag Analysis.

Proportion correct T1 identification plotted as a function of the lag of T2 presentation. Error bars indicate standard errors.

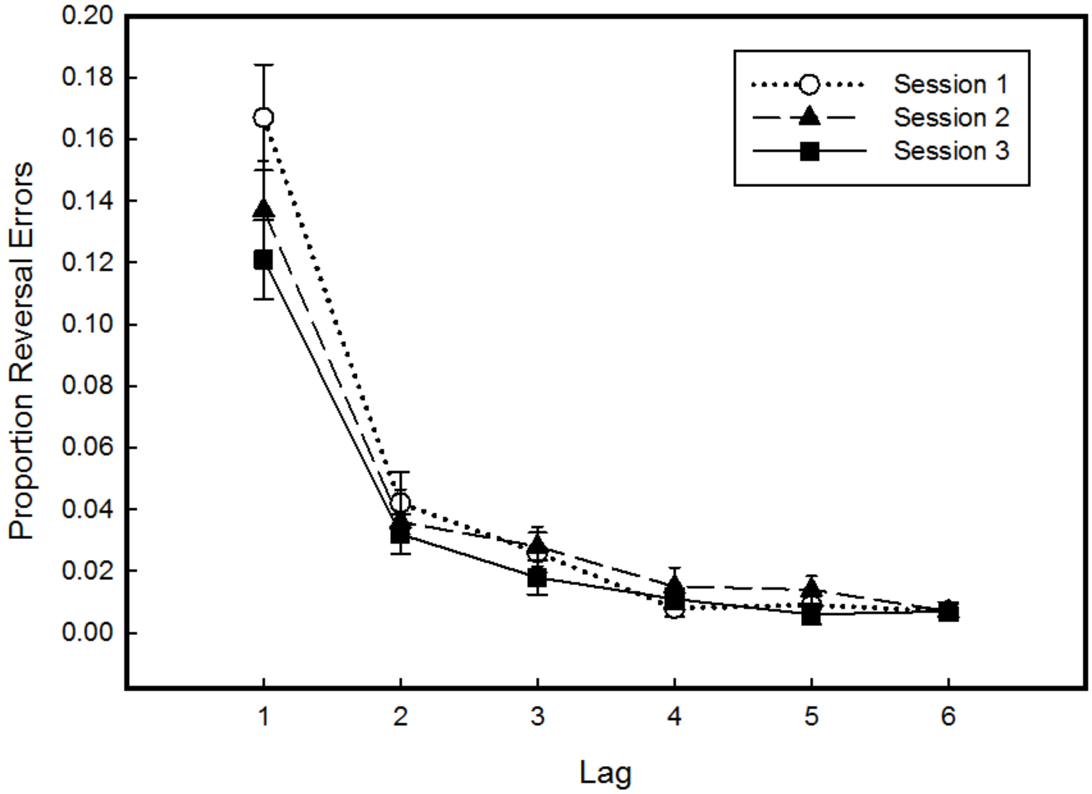

Figure 5. Results of Reversal Errors Analysis.

Proportion reversal errors as a function of Lag. Error bars indicate standard errors.

APPENDIX A: DEMOGRAPHIC QUESTIONNAIRE

This questionnaire is intended to gather demographic information for statistical analysis only. Your responses to this questionnaire will be linked only to your three-digit numerical identification code and you will not be identifiable by name.

1. What is your gender?
    a. Male
    b. Female
2. What is your date of birth? ____________
3. Are you left-handed, right-handed or ambidextrous?
    a. left-handed
    b. right-handed
    c. ambidextrous
4. How would you classify yourself?
    a. Asian or Pacific Islander
    b. Black / African-American
    c. White / Caucasian-American
    d. Hispanic
    e. Latino
    f. Native American
    g. Multiracial
    h. Other
    i. Would rather not say
5. How many years of education have you completed? ___________
6. Do you play video games regularly?
    a. Yes
    b. No
7. If you answered yes to Question 6, then please estimate how many hours per week you play video games. _________
8. Do you meditate regularly?
    a. Yes
    b. No
9. If you answered yes to Question 8, then please estimate how many hours per week you meditate. _________

APPENDIX B: PERFORMANCE QUESTIONNAIRE

This questionnaire is designed to gather information about your own subjective evaluation of your performance. Your answers to these questions will not affect your compensation for the study in any way. Please answer the following questions to the best of your ability:

1. If you consider all three experimental sessions, averaged together, what percentage of trials do you believe you accurately identified the targets:

    - First target only ________
    - Second target only ________
    - Both first and second target ________

2. During the first experimental session, what percentage of the targets do you believe you identified accurately?

    - First targets _________
    - Second targets _________
    - Both first and second target _________

3. During the second experimental session, what percentage of the targets do you believe you identified accurately?

    - First targets _________
    - Second targets _________
    - Both first and second target _________

4. During the third experimental session, what percentage of the targets do you believe you identified accurately?

    - First targets _________
    - Second targets _________
    - Both first and second target _________

Participant's three-digit identification number ______________