The Pennsylvania State University
The Graduate School
College of the Liberal Arts

IMPLICATIONS OF CONTROL

IN ROUTINE SKILLED PERFORMANCE

A Thesis in
Psychology
by
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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

August 2009

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Abstract

This thesis describes a series of experiments that were conducted to examine the influence of certain types of external actions and certain forms of goal criteria on routine skilled performance. Two preliminary experiments and three main experiments using an event counting task demonstrated that when external actions were made to control the timing and appearance of environmental information required for one-to-one binding with internal information, this binding became less or more successful under different control conditions. The type of goal criterion used in assessing task completion also influenced performance and suggested that internal forms of a goal criterion may be more beneficial to routine performance than external forms that necessitate monitoring for environmental events.

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Chapter 1. Introduction

Routine tasks such as counting are typically completed quickly, with relative ease, and under a variety of situations. Consider counting the number of books on a bookshelf. Although the effort required to count the books seems quite minimal, success relies on the careful coordination of internally generating numbers with shifting attention to each book in such a way that no one book is counted twice or skipped over entirely. In some situations this coordination effort may be aided by the ability to mark the items by using some form of external control, such as pointing to the individual books as they are counted. It may even be the case that the items can be easily moved or manipulated. For instance, perhaps the books are to be taken down from the shelf and boxed, and thus can be counted as they are individually handled.

Another important facet of counting is determining when to stop. It may be that only twenty books are to go into each box, and thus counting should stop after the twentieth book for each box has been added. On the other hand, perhaps someone else is organizing or boxing the books and the task is to merely hand off each book to that person and count the number of books taken off the shelf so far until that person determines when to stop. As these examples illustrate, the routine task of counting is rich with options and means for control that may or may not facilitate success (accuracy). As an exemplar of routine skill, counting may be used to compare and contrast the effectiveness of different means of control across various situations in order to examine their relative benefit to performance.

In the past, counting has been studied as an instance of routine mental activity because of its cyclic, sequential nature and well understood subprocesses. This basic task provides an experimentally manageable means for examining how people regularly complete routine cognitive tasks efficiently and skillfully with seemingly little conscious effort. Counting a number of items or events requires the subprocesses of retrieving sequential digits from memory, directing attention to individual items, assigning discrete digits to distinct items, and keeping a running total in working memory (Carlson & Cassenti, 2004). This reliably sequential series of subprocesses allows experimenters to manipulate the temporal and spatial parameters of counting tasks, such as the timing and discriminability of events, in order to expose how and when these subprocesses lead to successful performance. For instance, Carlson and Cassenti (2004) found counting to be more successful when events occurred at rhythmic intervals, but also that errors (when they occurred) tended to go undetected more often when counting was rhythmically paced. As an explanation, they suggested the process of counting to be guided by states of working memory that specify numbers and events deictically (i.e., non-semantically) and that errors are detected in an implicit manner by simply recognizing when fluency appears to be interrupted (Carlson & Cassenti, 2004).

Carlson and Cassenti (2004) diagramed the subprocesses involved in event counting as a cycle of retrieving, attending, and updating in what they called the intention-outcome cycle of event counting (see Figure 1.1). Their model depicted how the subprocesses of event counting can be understood in terms of the hierarchical structure of a goal, consisting of a plan, intention, procedure, and outcome. From an overarching *goal* to determine the total number of occurring events, each cycle begins with a *plan* to assign the next number in memory to the next occurring event. Following the plan comes a more specific *intention* to assign the currently activated number in memory to the immediately occurring event. A *procedure* then consolidates this newest number as the numerical total held in working memory and guides the shifting of attention to the next event. The updated total comes to represent the *outcome* of that cycle. Coordination and synchronization of numbers with attention to events is vital (Carlson & Cassenti, 2004) and has the potential to be influenced by a myriad of external and internal factors ranging from environmental distractors to internal confusions between intended numbers and current totals.

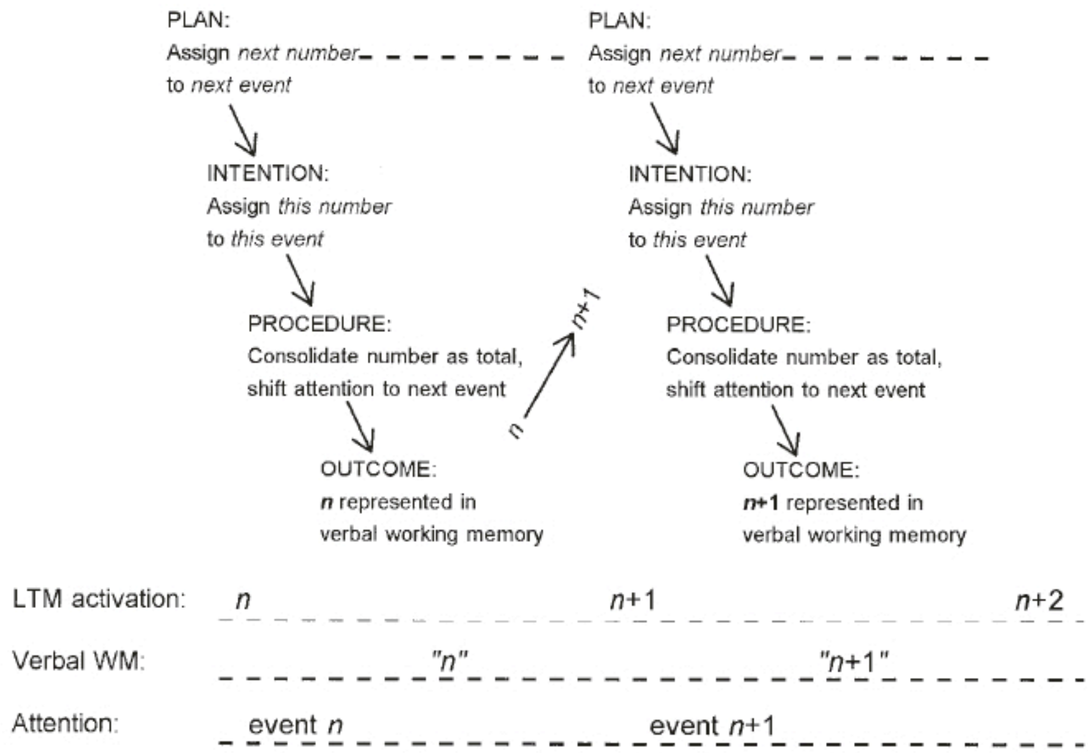

Figure 1.1: The intention-outcome cycle of event counting diagrammed by Carlson and Cassenti (2004).

In a slightly broader sense, this synchronization effort was examined by Carlson and Stevenson (2002), who coined the term *temporal tuning*, referring to the process of progressively adjusting the timing of mental operations to match the availability of external information on which they operate. It is this process that enables increasingly efficient performance of skilled activity, as temporal estimation is used to better coordinate internal and external events. With increasing skill and fluid performance, one is less likely to rely on the completion of one step in a routine task before considering the next. In fluent counting for example, one might learn to begin shifting attention to the next item while finishing the subprocess of updating the current count, with the assumption that by the time the next item is in focus, it will be ready to be counted. In this way, information from the environment may become available to working memory more closely to the time it is needed, preventing lags in time that can lead to loss of information or confusion with other information (Carlson & Stevenson, 2002). By closely timing the arrival of external information (such as an item or event) with its corresponding internal subprocess (updating a running total), one can facilitate an appropriate binding of external and internal events to produce smooth and accurate performance (Carlson & Stevenson, 2002). It is this component of skill acquisition that contributes to improved accuracy and efficiency for performing routine tasks with increasing practice.

1.1 Internal and External Components of Fluent Counting

To more explicitly consider the importance of, and the coordination between, internal and external events during the processes of counting, a model of event counting that highlights the temporal relation of these components is presented in Figure 1.2. The model is based on Carlson and Cassenti's (2004) model of event counting but departs from the fine granularity used to describe the intention-outcome cycle of fluent counting. Instead, the present model outlines three global stages of event counting that group the occurrences of internal and external events. In doing so, it may be easier to specifically examine how such events interact during a routine task in which coordination of internal and external information is vital to successful performance.

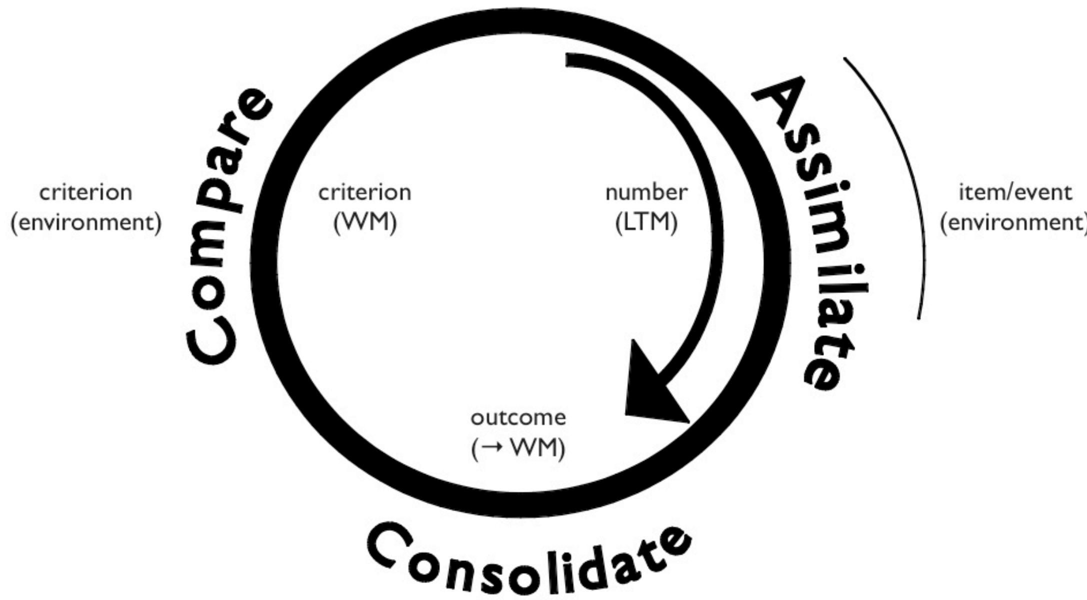

Figure 1.2: A proposed cyclical model of event counting, depicting the relationship between internal and external information during three consecutive processing stages.

Progressing clockwise, the first stage of the model – termed the *assimilate stage* – depicts the internal event (number activation in long-term memory) and external event (occurrence of to-be-counted items) that must be coordinated for temporal tuning. With practice, improvements in temporal tuning facilitate the appropriate binding of numbers to items that fulfill the one-to-one principle of counting (Gallistel & Gelman, 1992). It is important to note that prior to the occurrence of the internal and external events, the intention to assign the next number to the next item is represented schematically, with no specific reference to any one number or item, other than a deictic reference such as *this number* and *this item.* Consequently, the two parameters of the intention do not become specifically realized or filled in until the actual occurrences of the internal and external events, which may occur independently and apart from one another in time.

Temporal distance between the activation of a number in long term memory (LTM) and the occurrence of the item/event in the environment may lead to confusion errors and inaccurate counting (Carlson & Cassenti, 2004). In these situations, ambiguity between intentions and outcomes of counting cycles arises when a number becomes activated in LTM too long prior to or after the time that the item to be counted appears. If the number becomes activated long before the item occurrence, then it may become uncertain whether the active number is in fact active because it is intended to be assigned to the current item or instead because it has just been assigned to the last counted item and represents the active outcome (i.e., the total count) of the previous counting cycle. If it is erroneously decided then that the active number represents the outcome of the previous cycle, the next number in LTM will become activated and assigned to the current item to represent the updated total, leading to an overcount error (Cassenti & Carlson, 2008). If instead, it is correctly decided that the active number represents the intended number to be assigned to the current item, accurate updating of the total will result and no error will occur. Alternatively, undercounting may arise if the item to be counted occurs too far prior to the activation of the current number to be assigned in LTM and that item is erroneously judged to be part of the outcome (i.e., the counted item) of the previous counting cycle. In this case, the current number will be assigned to the next item instead. These scenarios illustrate the importance of synchronization between internal and external events in the assimilation stage of event counting.

Once both the internal and external events of the assimilate stage have been bound, the active number representing the outcome – or updated count – of the cycle is stored in working memory (WM) as the current total during what is termed the *consolidate stage*. Consolidation of the outcome is important for both tracking the updated total and for potentially deciding the point at which counting is to cease.

Internal and external events may then be used during the *compare stage* of the counting cycle to determine whether counting is to proceed or end with the current counting cycle and current total. During this phase, an external event (i.e., a signal from the environment) may serve as a criterion for discontinuation, or alternatively, some internal information in working memory (e.g., a target number) may be compared to the current state of counting to determine the completion of the task. For instance, if no more items remain to be counted, this environmental signal (i.e., the absence of items) should specify that the current outcome is to be considered the final total and counting should end. If such a signal goes undetected or perhaps mistakenly detected, counting may proceed or discontinue in error. Alternatively, it may be that once a desired number of items has been counted, counting should end. In this case, a comparison between the current cycle's outcome and a target number held in WM is made in order to determine when the final counting goal has been reached. Likewise, if such a comparison is neglected or carried out incorrectly, counting might proceed or discontinue prematurely in error, which would likely result in a miscount.

In summary, Figure 1.2 illustrates the important occurrence of, and interaction between, internal and external events as they relate to routine counting. Accurate and efficient performance is likely to be influenced by the temporal relation of these events – most notably during the assimilate stage of counting – and perhaps by the type of event (internal or external) used as a criterion for the compare stage of counting. Whether these facets of control for fluent counting reliably affect performance or interact to influence performance is to be determined.

1.2 External Event Control and the Placement of Internal Markers for Temporal Tuning

From understanding the importance of coordination, especially in rapid cognitive tasks such as event counting, it seems reasonable to question whether temporal synchrony for the binding of internal and external events during assimilation might be more easily achieved in some situations than in others. Since temporal tuning of performance can be achieved by adjusting the timing of information retrieved from the environment, perhaps certain means of doing this are most effective. For instance, it might be the case that controlling the initiation of when information becomes available provides an easier way of matching internal to external events than controlling when information that is no longer needed may be dismissed. These two forms of external event control might in essence mark two different points in the assimilate stage of the counting cycle. Controlling the initiation of information onset could provide a marker for the beginning of the external event in the assimilate stage, whereas controlling the dismissal of external information could provide a marker for the end of that external event.

An advantage of one marker location over another seems ambiguous until one considers relevant findings from the motor control literature that address the topic of synchronization, and until one reflects on common scenarios in which one type of control (and its corresponding cycle marker) would seem to be most favorable. In the motor control literature, evidence of a bias towards synchronization with early-occurring external stimuli over late-occurring external stimuli during tasks in which people control the rhythmic tapping of their own fingers in relation to given tempos (Repp, 2003) illustrates a nonconscious temporal attraction for one phase of a rhythmic cycle over another. In the language of temporal tuning, the internal generation of a consistent pace for finger tapping seems preferentially tuned to an early external phase marker of the rhythmic cycle. With time, these internal and external events become more closely bound and finger tapping becomes synchronized with the earlier tempo.

Common tasks in which control can be used to determine the timing of external events also demonstrate preferential means of temporal synchronization. For example, one might decide that in order to effectively count the number of books on a bookshelf, they will point to each book as they are ready to count it, generating a point-then-count routine that emphasizes control for the initiation of external information. On the other hand, to count a stack of dollar bills, one might decide it best to hold the stack in one hand and use the other to count and lay each bill aside as they go, generating a count-then-lay routine that emphasizes control for the dismissal of external information. In this way, external event control – governing the time at which external events occur – is used to time the arrival or departure of relevant environmental information in relation to the time it is needed by internal processing. Control for the timing of external events should thus provide an opportunity to mark specific points of the counting cycle and allow for better precision in matching internal and external events, a process critical for accuracy. It seems reasonable to expect that one form of external event control might be most beneficial for a given task, provided that strategies for counting seem to vary systematically across different tasks. For instance, most people would presumably opt to point to each book on a bookshelf while counting instead of employing some other external control method, such as pulling each book from the shelf as it is counted (unless, of course, the books were to be taken down from the shelf for some other purpose). In contrast, most people would likely prefer to push or pick up coins as they are being counted, instead of merely looking at the coins laid out in front of them.

1.3 External Event Control and the Properties of Internal Markers for Temporal Tuning

Besides offering markers for different phases of the counting cycle used for timing and coordination, one might consider whether certain forms of external event control might elicit more salient – and thus perhaps more effective – markers than others. The effectiveness of marking a point of the counting cycle might depend not only on the time at which external events are controlled, but also on the extent to which that control marks or delineates an event's temporal position in the counting cycle. For instance, it may be that the sound of coins dropping into a glass jar as they are counted creates a more salient temporal marker of external events than the soundless act of handing off each coin to another person as it is counted. Both forms of control should be physically similar and mark the end of the external event, but might lead to differences in the tractability of events and resulting outcome accuracy.

On the other hand, it might be that some highly salient external events do not facilitate the marking of cycles for a given task. Perhaps the salient feature of an external event occurs at a temporal distance from the controlling action, making it difficult to use that salient feature as a marker for temporal tuning. For example, if one were to count stones being dropped into a well, it would seem less than ideal to use the sound of each stone eventually hitting water as an internal marker for temporal tuning, despite the relative salience of the sound. In such a case, a high-salience external event might be more distracting than helpful, pulling attention away from internal events pertaining to LTM activation or WM consolidation and toward perceptual processing of external events instead. Such distraction could prove detrimental to processes guiding efficient and accurate performance if it leads to information loss from working memory.

In summary, if control for external events can in fact influence the effectiveness of temporal tuning, it is unclear whether more conspicuous perceptual indications of such control should facilitate the binding process or instead disrupt it, or whether this might depend on the form of control used during counting and other factors. In order to unpack the potentially complex role that external event control might play in the success of routine task performance, both the timing and perceptual properties of controlled external events is to be examined.

1.4 Internal and External Control for Counting Discontinuation

Beyond the assimilate stage of counting, both internal and external events play a vital role in providing information about when counting is to continue or discontinue during the compare stage of counting. As previously mentioned, once the currently updated total has been consolidated in working memory, that number might be compared to some goal number to determine if the desired number of items has been counted. This internal event (i.e., the comparison between the current and target number) may be used to control the progression of counting. If the current total does not yet match the target number, the internal criterion for counting discontinuation will not have been met, and counting should proceed into the next cycle (see Figure 1.2). If on the other hand, the criterion has been met and the numbers match, counting should stop. Alternatively, an external event may be used to signal the discontinuation of counting. In this case, the criterion for counting discontinuation will be the occurrence of some external signal in the environment. Once this external signal takes place, the criterion for ending the progression of counting cycles has been met and counting should stop. For example, it may be decided that counting will go on until another person dictates when to stop, or until there are no more items to be counted.

Internal and external forms of control for the compare stage of counting each require correspondingly different demands on cognition. The goal of counting to a designated number of items (using an internal criterion for the compare stage) emphasizes maintenance of a target number held in WM. In contrast, counting toward the occurrence of some external signal (using an external criterion for the compare stage) emphasizes monitoring of the environment for the relevant stop signal. These differences in cognitive demands may have implications for performance, as WM and attentional resources are required to carry out the task of counting.

Correspondingly different means for representing the two forms of counting goals might also exist, having potential implications for performance. Beyond the demand of environmental monitoring, counting goals for which the discontinuation criterion exists externally may require more abstract, i.e., less explicit, representation than counting goals for which the discontinuation criterion exists internally. By having a more abstract representation of the task's end state, counting with an external goal criterion may progress slower and less smoothly, as the end state (external signal) may occur at any time. In this case, fast progression of counting might increase the risk of failing to detect the external signal's occurrence in time to prevent the progression of counting into the next cycle. In failing to promptly detect the external signal, a miscount may likely occur. In contrast, having a more explicit representation of the task goal by using an internally held criterion may afford one to progress more quickly and smoothly while counting, as the end state is more predictable and may be internally estimated.

1.5 Control and Metacognition for Errors

For rapid, skilled activities such as counting, the highly conscious and effortfully controlled process of explicit monitoring is often abandoned in favor of a more automatic, implicit approach to monitoring performance (Carlson & Cassenti, 2004). Implicit monitoring facilitates faster, more schematic execution of cognitive tasks by using the fluent nature of skilled activity as a baseline against which disruptions in smooth performance indicate possible errors (Carlson & Cassenti, 2004). Since temporal tuning contributes to this fluency, forms of external event control that differentially affect the use of temporal tuning in the assimilate stage of counting might also differentially affect the use of implicit performance monitoring. Increased fluency via temporal tuning may benefit speed and overall accuracy, yet make it more difficult to detect one's errors. Carlson and Cassenti (2004) found the emergence of implicit monitoring strategies in skilled performance to be marked by the occurrence of undetected confusion errors, despite lower overall rates of error with increased skill. This finding is in line with Efklides' (2009) assertion that metacognitive experiences, like those involved in giving confidence ratings of performance, take place continuously on a nonconscious, implicit level. Consequently, if certain forms of external event control contribute to enhanced fluency of performance, it might be expected that, while errors should occur with less frequency, the errors that do occur may often go undetected and uncorrected.

Similarly, internal and external events in the compare stage of counting that might impact the fluency of performance, might also influence how performance is monitored By promoting slower, less fluent processing in order to avoid counting past the desired number of items, counting with the goal of meeting an external criterion is likely to encourage more deliberate monitoring. Consequently, although the pace of counting will likely be slower and less smooth when using an external criterion for counting discontinuation, performance might also tend to be more successfully monitored and errors more often detected when doing so.

1.6 Summary

The aim of the current thesis was to compare different means of control across various counting situations in order to examine the influence of control in routine task performance. The role of external event control in supporting the subprocesses of the assimilate stage of fluent counting, the role of internal and external criteria used for control of the compare stage, and metacognitive monitoring of performance were all examined. The contribution of several possible mechanisms accounting for such control effects were tested, including the manner in which control is represented, the relative placement of internal markers used for temporal tuning, the properties of those internal markers, and cognitive demand differences. As it was likely that several of these mechanisms should interact to influence performance, experimental manipulations were used to combine factors of control in order to explore their potential interactions. In other words, it was expected that certain forms of external event control would be more (or less) beneficial to performance during situations in which counting proceeded to some internal (or external) goal criterion. It was also important to examine the possible interactive effects of control at just the assimilate stage of counting, as it was expected that the effects of timing and the appearance of external events might converge to affect temporal tuning at the assimilate stage in different ways. For instance, it was possible that control for external events that have highly salient properties and occur immediately following one's action would provide more of a benefit to temporal tuning and the binding of internal with external events than control for immediate/low salience events or delayed/high salience events. In this case, both the relative placement of internal markers along with the properties of those markers (as well as perhaps even the representation of control) might have been found to interact to provide substantial benefits to counting performance.

A series of experiments were conducted to compare various forms of control in an event counting paradigm in which measures of accuracy, speed, and confidence could be used to determine the implications for routine task performance. Before describing these experiments, two preliminary experiments and their findings will be summarized to provide a backdrop for the current experiments. The two preliminary experiments were part of a small set of experiments previously conducted to begin addressing the questions described above. Differences in control for the timing of external events during the assimilate stage were compared as a first step to understanding how control might influence performance. Since the effects of external event control might be attributable to the nature of the controlled events (timing, physical properties, etc.) or to how such control is internally represented, it was important to examine situations in which little true external control differences existed, yet representational differences were likely. The preliminary experiments were designed such that both the onset and offset of external events were controlled with one single action, and thus true external control was relatively consistent between conditions. In one case, an action would control the onset and then offset of an external event during counting, while in another case, an action would control the offset and then onset of an external event. However, instructional and relative temporal distance between an action and the onset/offset of the external event differed in such a way that the *representation* of such control would likely differ. For instance, actions for which the onset and then offset of events would occur were described instructionally as (and thus potentially represented as) ‘turning on’ type actions. Actions for which the offset and then onset of events would occur were described as ‘turning off’ actions

In later preliminary experiments (not covered in detail here), the role of internal and external control at the compare stage of counting was investigated. In sum, preliminary experiment results suggested that the representation of control for the assimilate stage of counting and the type of criterion used in the compare stage of the counting cycle both affect performance and metacognition. In order to clarify the complex notion of control representation and to introduce the designed experimental paradigm for this project, Chapter 2 will describe two preliminary experiments that compared similar forms of external event control at the assimilate stage in order to examine the role of control representation. The three main experiments of this thesis were then designed to further address the topic of control during routine task performance.

Chapter 2. Preliminary Experiment Overview

The following set of experiments was designed and carried out as a prefatory inquiry into the relationship between different means of control and resulting routine task performance. Since, to the best of my knowledge, the details of this topic have not yet been addressed or reported on in the cognitive psychology literature, it was necessary to conduct simple pilot experiments in order to establish whether such effects of control might exist.

To begin investigating this topic, representations of control were first examined. In two preliminary experiments, instructional and procedural variations were used to manipulate participants' representation of control for the occurrence of external events in the assimilate stage of an experimental counting task. Before examining how true differences in external event control might affect performance, it was decided to test whether simple representational differences (with little difference in true external event control) might affect performance. For instance, if the timing of both the onset and offset of external events is equally controlled, perhaps representing control as primarily one form over another (controlling the onset versus the offset of counted items) may be more beneficial to temporal tuning and resulting performance. Put differently, representing external control as causing items to *appear* so that they may be counted might result in better or worse performance than representing control as causing the *disappearance* of items once they have already been counted. Similarly, it might be the case that errors in counting are more readily detected when representing external event control in one manner over another. Such examinations of external control might serve to elucidate why certain forms of control are more often chosen over others while carrying out simple counting tasks such as counting money or books on a bookshelf.

One preliminary experiment aimed to determine whether a relationship between representation for external event control and performance for simple routine counting tasks might exist. A second experiment was then used to examine the extent to which such representation of control is likely to influence performance on subsequent trials of a counting task in which a different representation of control for external events is called for instead. A computerized event counting task was designed to control the fast, repetitive display and timing of events. To address the question of whether representation for external event control might particularly influence metacognitive processing, ratings of answer confidence were collected after each trial as an indication of error detection.

Chapter 3. Preliminary Experiment 1

Two forms of external event control for the assimilate stage of counting were examined using a computerized counting task that allowed for control to be timed to the beginning or end of external events. In one condition, participants controlled the initiation of information from the environment by governing the onset of events to be counted. In a second condition, participants controlled the dismissal of information from the environment by governing the timing of event offset.

Because items were counted as they appeared individually on a computer screen, the computer program controlled remaining actions for each cycle, clearing an item in preparation for the next keypress in the event onset control condition, and displaying the next item shortly following a keypress in the event offset control condition. In this sense, performance in both conditions led to equal control for both the initiation and dismissal of external information, with one of the controlled effects occurring more temporally proximal to the moment of a keypress than the other. It was assumed that the controlled effect occurring most immediately after the keypress would be perceived as the primary (if not only) effect of the controlling action, and therefore become the predominant feature in the representation of external event control for the task. Thus, the occurrence of this most immediate action would likely be used as a temporal marker of counting cycles. To promote and compare the two representations of control, participants were asked to count events by either controlling the ‘turning on’ or ‘turning off’ of items as they counted. According to Carlson and Stevenson’s temporal tuning hypothesis (2002), participants controlling the immediate offset of items should be readily able to temporally tune their performance to the onset of items if this form of control is most preferred or beneficial to performance, despite their more temporally removed means of such control. Likewise, those controlling the immediate onset of items should be able to temporally tune their performance to the offset of items if desired or beneficial. As a result, there is little true difference between the onset and offset control conditions in this task, making the examination of control representations effects possible. To do this, participants performed each of the two forms of control for twenty successive trials, with the order of the two control tasks determined at random for counterbalancing purposes.

3.1 Method

3.1.1 Participants

Forty-six students enrolled in introductory psychology courses at The Pennsylvania State University participated in exchange for a small amount of course credit.

3.1.2 Materials

The experiment was programmed using E-Prime, version 1.1 software to run on Windows-based personal computers. Instructions and stimuli were presented on CRT monitors, and participant responses were collected via standard computer keyboards.

3.1.3 Design

Each participant was randomly assigned to the event control condition that would be performed first, grouping half of the participants in the onset control condition and the other half in the offset control condition initially. Participants completed 20 trials of each control condition separated by a short break.

3.1.4 Task and Procedure

Each participant completed the experiment individually after signing an informed consent document for participation. The experiment was conducted in a small room lit by a desk lamp, where each participant was seated at a computer and instructed to keep a running count of white 18-point font asterisks as they appeared one at a time on the screen. The task consisted of 40 self-paced event counting trials, requiring less than 30 total minutes to complete, and once finished, participants were thanked for their time, debriefed about the purpose of the experiment, and dismissed.

To begin the counting task, computerized instructions informed half of the participants that by pressing the keyboard's enter key, a white asterisk would appear briefly in the center of the screen for them to count, and that this could be repeated until there were no more asterisks left to be counted for that trial. Once all asterisks had appeared, an answer box would prompt them to enter the total trial count. Trials began with a blank screen that remained until the participant pressed the enter key to display an asterisk (see *controlling onset* portion of Figure 3.1). An asterisk would appear for 250 ms then leaving the screen blank until the participant pressed the enter key again to initiate the onset of the next asterisk. Counting continued in this manner until the final asterisk appeared and the participant was prompted to enter the total number of asterisks for the trial.

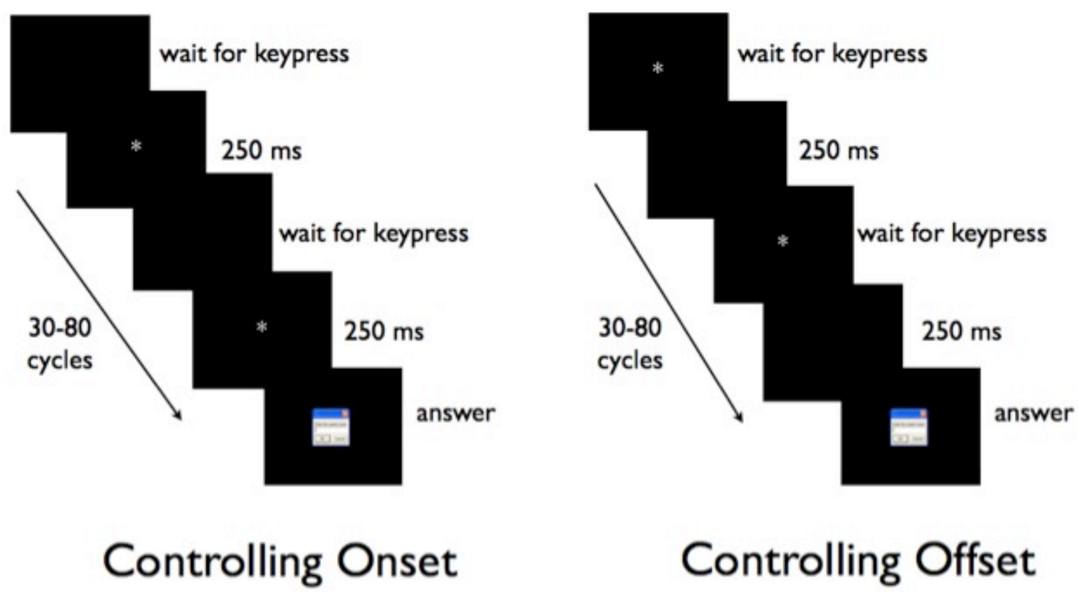

Figure 3.1: Preliminary experiment task schematic. The controlling onset condition began with a blank screen followed by the 250 ms display of an asterisk whenever a keypress was made. In the controlling offset condition, the display of an asterisk disappeared for 250 ms whenever a keypress was made.

The remaining participants were instructed that an asterisk would be visible on the screen until the enter key was pressed to clear it. Asterisks would continue to appear one at a time in this fashion until no more asterisks were left to display and an answer box requested the total count. Trials of this condition began with an asterisk in the center of the screen that remained until the participant pressed the enter key, at which time it would disappear (see *controlling offset* portion of Figure 3.1). The screen then remained blank for 250 ms after which the next asterisk would appear until the enter key was pressed again by the participant to clear it. Delays of 50 ms occurred between keypresses and their effects.

Participants were informed that pre-determined numbers of asterisks had already been chosen for all trials, and that a short break would be given halfway through the experiment. Each trial began when the participant indicated that they were ready by pressing the space bar. After entering the total count for a trial, participants were prompted by the computer to rate their answer confidence on a scale from 1 being low to 5 being high. They were then shown a feedback screen either confirming their correct answer or disconfirming their answer by revealing the true count.

Trials contained a number of asterisks randomly assigned from 30 to 80 at the start of each trial. Participants were given the option to press a stop button (the keyboard’s ‘a’ key) in the event that the count had become irretrievably lost during a trial. This way the participant would avoid having to press the enter key a number of times to reach the end of the trial. Pressing the stop button would immediately prompt the answer box to appear, followed by the confidence prompt and feedback display. Once all 40 trials were completed, participants saw a thank you screen to signal the end of the experiment.

3.2 Results

It was hypothesized that performing the event offset control condition would lead to better counting accuracy than performing the controlling-onset condition. This prediction arose from a postulation that the offsetting of events might be analogous to a mental representation of ‘checking-off’ items as they were counted, and that this would serve as a more effective timing marker for temporally tuning the internal mental processes with the external events, by marking the end of external events.

Two of the 46 participants were excluded from data analyses due to low overall accuracies around 20%, and another participant was excluded as a result of confusion concerning the experimental instructions for the task, which resulted in incorrectly carrying out the task procedure. Of the 43 remaining participants, 21 completed the onset control condition first and 22 participants completed the offset control condition first.

Trials in which the stop button was pressed were excluded from statistical analyses, although participants rarely chose to use the stop button to prematurely end counting trials. The stop button was pressed on average 1.4 times over the

40 experiment trials, and only 14 of the 43 participants had made use of the stop button at all, suggesting that it was properly used to end trials for which the count had become irretrievably lost.

3.2.1 Accuracy

Participant accuracy data revealed a significant interaction between the control condition and the order in which the condition was performed $F(1, 41) = 6.71$, $p < .05$. Accuracy for the onset control condition varied significantly depending on when it was performed in relation to the offset control condition, $t(41) = -2.40$, $p < .05$. When performed first, mean accuracy for the onset control condition was 77.8%, but when performed second, following the offset control condition, mean accuracy was only 63.2% (see Figure 3.2). In contrast, counting accuracy for controlling the offset of events did not differ with the order in which it was performed, and mean accuracy percentages equaled 69.5% for both initial performance and performance following the control of event onset. Taken together, these results suggest that differences in the representation of task control can in fact impact task accuracy and the transferability from one form of control to another within a short amount of time.

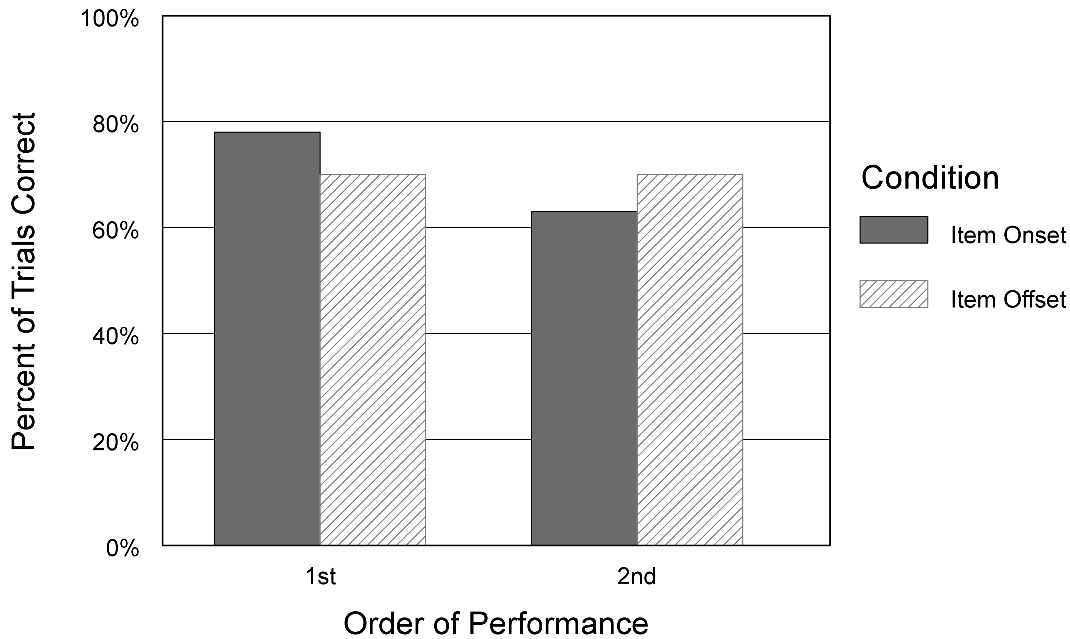

Figure 3.2: Accuracy results of preliminary Experiment 1.

Beyond the effects of control, both groups of participants experienced a decline in accuracy from the first half of the experiment to the second (onset-offset group: 78% to 70%; offset-onset group: 70% to 63%). Although this order effect was not significant, it brings into question the extent to which carry-over effects of the two representations of control can instead be attributed to fatigue or motivational factors. In order to address this question, the second preliminary experiment examined changes in accuracy over the duration of the experiment without shifting control conditions.

3.2.2 Errors

Overall, most errors were the result of overcounting as opposed to undercounting. The mean signed error for the onset control condition was 0.42 and was 0.13 for the offset control condition. Both control forms also appeared to have detrimental effects for transferring to the second control condition for the task, suggesting that representations of control may be difficult to modify or replace after even little to moderate amounts of consistent use.

Following the control of event onset, mean absolute error increased from 0.93 to 1.38 when participants were required to switch to controlling the offset of events during the second half of the experiment. Similarly, the mean absolute error for initially performing the offset condition was 0.82, followed by 1.21 after switching to the onset control condition.

3.2.3 Metacognition for Errors

Retrospective confidence judgments were used as a measure of metacognition for errors by comparing ratings given directly after correct and incorrect trial performance. Because this type of counting task allows for many possible answers, successful detection of errors might not always lead to successful repair of errors and correct results. One could indeed have a sense that performance might not have gone smoothly, without explicitly detecting the precise moment of error and drawing on the right repair strategy to correct for it. Consequently, confidence data for correct trials might indicate lower than expected ratings if errors occurred but were then successfully repaired.

Confidence data for incorrect trials should however reflect both the detection of errors for which repair was either unsuccessful or unattainable and the confidence felt when errors were made but went undetected (which should likely be high). By excluding data for which absolute errors are greater than five (and thus unlikely to be sufficiently corrected despite detection), we can assume that most confidence data for incorrect trials reflects whether or not errors were detected during counting. If errors went mostly undetected, the mean confidence for incorrect trials should be similar to the level given for correct trials. If instead, errors were detected but inadequately repaired, confidence should be low. Of course, a limitation of this type of metacognitive measurement paradigm is the necessary assumption that repair success is able to be reliably reflected upon and judged.

Each participant’s metacognition for performance was calculated as the difference in mean confidence expressed following accurate and inaccurate trials in which the absolute error did not exceed five. On account of this difference score calculation, analyses for metacognition could only be gathered from participants who had been both accurate and inaccurate at performing the two conditions of control over the course of the experiment. Thus, confidence data for participants who performed 100% accurately (or inaccurately) on either one or both of the control condition blocks were necessarily excluded from metacognition analyses.

The form of control used to count events emerged as an important determinant of how well errors were detected, $t(37) = -2.15$, $p < .05$, as evidenced by error monitoring differences between the two initial control groups. In the first half of the experiment, those who controlled the onset of events rated their performance for successful trials an average of 0.71 of a point higher than for unsuccessful trials, whereas those controlling the offset of events showed only a 0.26 of a point difference between confidence ratings for successful and unsuccessful trials. This finding suggests that successful monitoring of performance is in fact influenced by the manner in which one controls the timing of external information (or represents that control) during routine task performance. For event counting, it appears that controlling the immediate onset of external event occurrences appears to be more beneficial to both performance accuracy and metacognition than controlling the immediate offset of events.

Despite worse monitoring of performance during the initial event offset condition in comparison to the initial event onset condition, the overall ability to monitor errors during event offset control significantly depended on the order in which this condition was performed, $t(37) = -2.62$, $p < .02$ (see Figure 3.3). Initial control for event offset was marked by rather poor monitoring for errors ($M = 0.26$) as previously mentioned, but when preceded by onset control, this monitoring was just as good as initial event onset control monitoring ($M = 0.71$). These results seem to again highlight the complex relationship of external control and the resulting performance and monitoring abilities associated with routine tasks. This marked parallel to the accuracy results, provides added support for a control representation account of the effects.

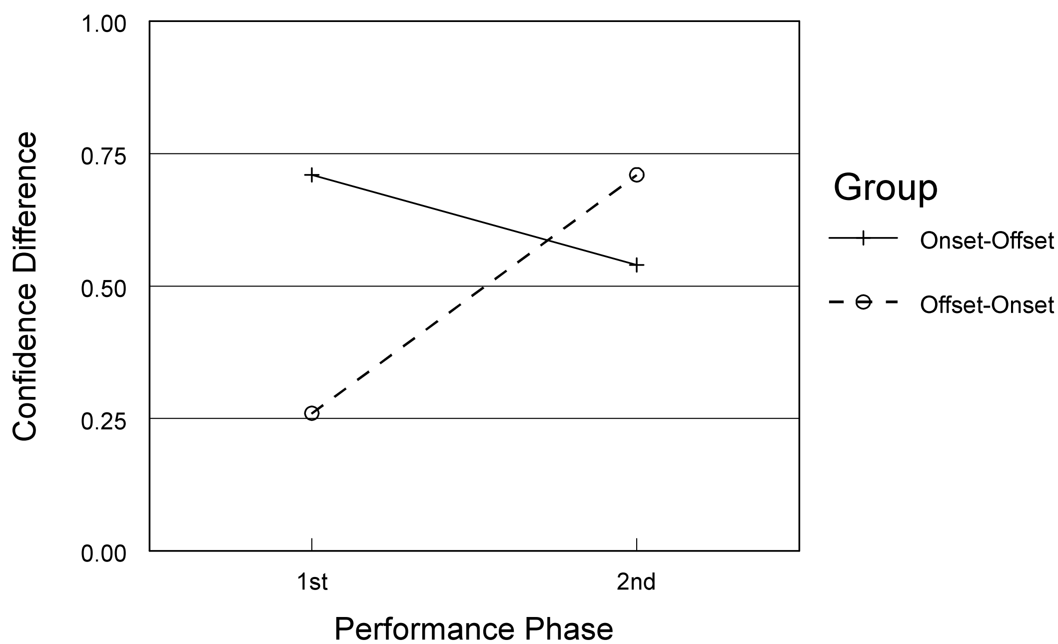

Figure 3.3: Metacognition results of preliminary Experiment 1.

3.3 Discussion

Differences in the performance of the two initial control conditions suggests that the way in which control for a task is represented can indeed affect how well a task is performed and how reliably errors are detected. This difference might be attributed to the level of facilitation for the binding of internal and external events for temporal synchrony. Representing control for the onset of events provides a temporal marker for the initiation of information from the environment (the onset of an external event), whereas representing control for the offset of events provides a marker of the termination of this information (the offset of an external event). Since both the immediate event onset and offset conditions enabled true control for both the timing of event onsets and offsets in this task, results suggest that the effects most immediate to one's actions are most salient in representing control. Assuming this is the case, it seems that representing control for the initiation of external events, as opposed to the termination of them, promotes more precise matching and binding of these events with internal processes (LTM activation).

Important to note however, is that both groups of participants showed a significant decline in accuracy from the first condition to the second. Because this decline did not occur equally between the two groups, it remains uncertain how much of the accuracy difference seen in the second block performance can be attributed to the carry over effects of the two representations of control and not to fatigue or motivation factors instead. Accuracy for performing the offset condition only differed by 2% when performed first versus second, whereas accuracy for performing the onset condition proved 15% higher when completed first. In order to assess the contributions of fatigue and transfer, it was important for a second preliminary experiment to be conducted to examine the extent to which performance might be apt to decline merely by continuing to perform the counting task without switching external control conditions.

Chapter 4. Preliminary Experiment 2

The second preliminary experiment was conducted in order to assess the degree of representational carry over effects suggested by the first preliminary experiment. The experimental task and procedure remained identical to that of the first preliminary experiment, with the addition of two conditions. As in the first experiment, participants either controlled the onset or offset of external events during each of two experimental blocks with random order of assignment. Two of the four participant groups performed 20 trials of each control condition, as participants in the first experiment had done. Participants assigned to each of the other two participant groups controlled either event onset or offset for all 40 experiment trials. The four participant groups will be referred to by their relative condition sequences: onset-offset control, offset-onset control, onset-onset control, and offset-offset control.

4.1 Results

Four of the 98 participants were excluded from analyses on account of low accuracy (< 30%). Of the remaining 94 participants, 22 completed the onset-offset control condition, 24 the offset-onset control condition, 23 the onset-onset control condition, and 25 the offset-offset control condition. Analyses mirrored that of the first preliminary experiment.

4.1.1 Accuracy

As shown in the first preliminary experiment, controlling the immediate onset of external events led to higher accuracy over controlling the immediate offset of events, F (1, 45) = 5.25, $p < .05$. This difference was demonstrated by performance in the two consistent control conditions (onset-onset mean: 81%; offset-offset mean: 68% - see Figure 4.1). This was also seen during first phase performance of the two groups that conducted both onset and offset control during the experiment, F (1, 44) = 10.72, $p < .01$ (onset-offset mean: 85%; offset-onset mean: 68%).

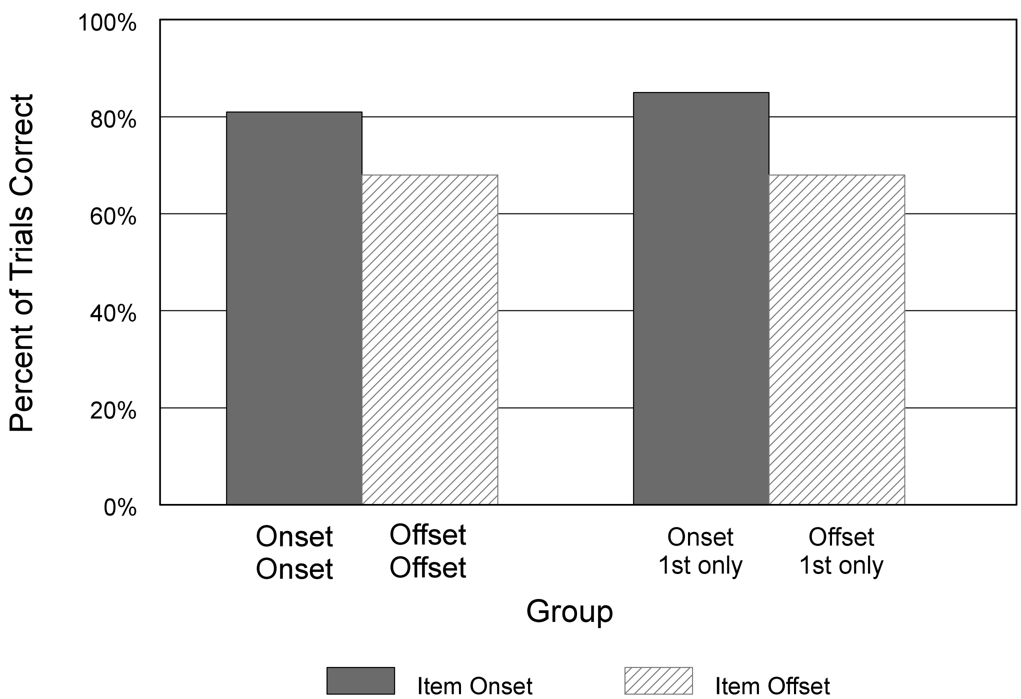

Figure 4.1: Accuracy results of preliminary Experiment 2 shown by group.

Interestingly however, and again in line with findings from the first experiment, this accuracy advantage for controlling the immediate onset of events was no longer seen in second phase performance after switching forms of external event control. Counting accuracy following the switch showed no advantage for immediate event onset control, and in fact revealed no difference between onset and offset control (onset-offset mean: 69%; offset-onset mean: 65% - see Figure 4.2). When performed second, onset control accuracy more closely resembled accuracy rates typical of the initial offset control condition (offset-first mean: 68%; onset-second mean: 65%).

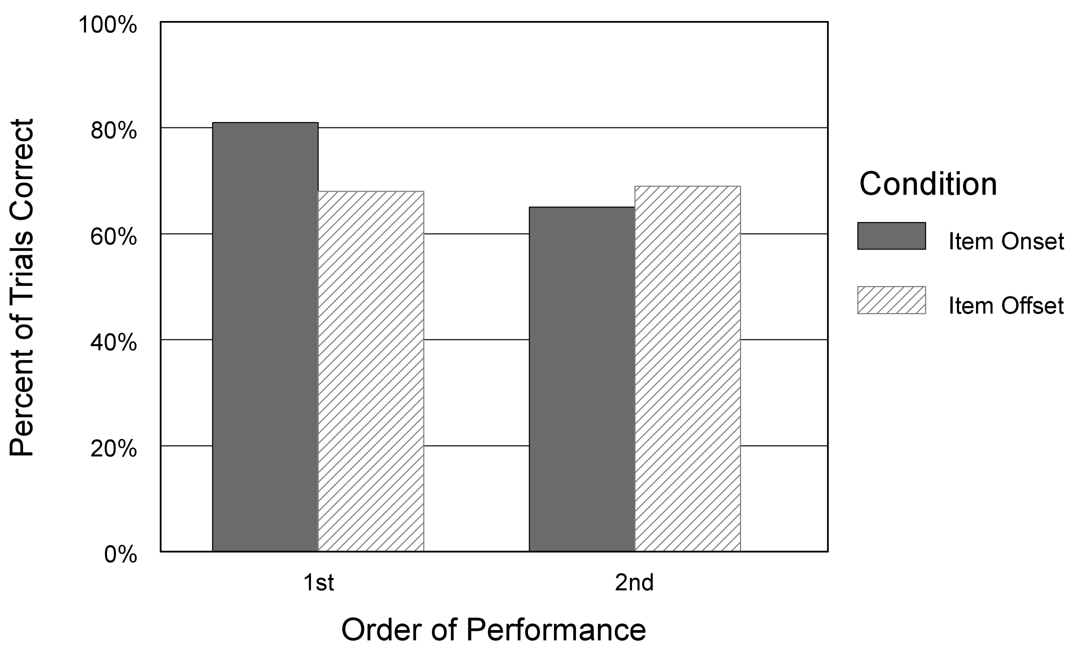

Figure 4.2: Accuracy results of preliminary Experiment 2 shown by control event type and order of performance.

Together, these findings again suggest a representational difference between control for the immediate onset versus offset of external events while counting. It also appears that representing the cycle of event counting with an emphasis for event offset control tends to be more resistant to decay when changing means of control.

With regard to the influence of fatigue/motivational factors over the duration of the task performance, decreases in accuracy again emerged from the first half of the experiment to the second in both the onset-onset (80% to 76%) and offset-offset (71% to 63%) control conditions, indicating some influence of continued performance on accuracy, $F(1, 46) = 6.61$, $p < .05$. However, this component alone was insufficient in accounting for the effects of transfer observed in both preliminary experiments, which was better explained by the interactive effect of the two control forms discussed above.

It should also be noted that the average time taken to complete counting cycles – calculated as the mean time in ms between button presses – was slightly shorter during performance of the event onset control condition $F(1, 92) = 3.07$, $p = .08$ (onset mean: 641ms; offset mean: 698 ms). This suggests that representing control for immediate event onset might encourage or enable faster counting performance.

4.1.2 Errors

Again, most errors were the result of overcounting – 8.7% of trials resulted in answers that were inaccurately low, and 14.4% resulted in answers that were inaccurately high. This trend applied to both event onset and offset control and over both phases of the experiment. The magnitude of those errors was slightly greater when the offset of events was controlled, but this difference was not significant (mean error for onset condition: 0.58; mean error for offset condition: 0.75).

4.1.3 Metacognition for Errors

Unlike the first preliminary experiment, group differences for metacognition judgments did not emerge, and confidence scale ratings for correct and incorrect answers did not reliably differ. While performing the onset control condition, confidence for correct and incorrect answers differed by 0.30, and while controlling event offset, this difference was 0.32. No order effects were observed for the groups in which both control conditions were performed over the course of the experiment.

4.2 Discussion

By experimentally manipulating task instructions pertaining to external event control, it was demonstrated that counting performance on both primary and secondary counting tasks can in fact be affected by how external events are controlled, or represented as controlled, during the assimilate stage of counting. Data indicating differential degrees of transfer from one form of immediate control to another suggest that these differences in performance are most likely attributable to representations of external event control. In this sense, it might be the case that control for item onset is represented as causing an event to occur or an item to appear, while control for the offset might be represented as causing an item to go away or disappear. Thus, the way in which external event control is represented might influence how effectively the task is carried out. This perspective is further supported by the fact that both experimental conditions allowed for control of both the initiation and dismissal of external information (item appearance). Despite having a more temporally removed means for controlling the initiation of information (item onset), those in the offset control condition should have been readily able to temporally tune their performance to the onset of asterisks if this was most preferred or beneficial to performance, according to Carlson and Stevenson's temporal tuning hypothesis (2002). With this being the case, it would seem that little difference truly existed between the onset and offset control conditions in this task, leaving a representational account for explaining the observed performance difference appealing.

Still plausible, however, is a more perceptual explanation of the observed performance effects. It may be the case that performance differed between conditions of external event control on account of a difference in the relative salience of the events themselves. In this case, controlling the onset of a bright asterisk may have been a highly salient event for which its occurrence was more easily used for marking a point of the event counting cycle and temporally tuning performance If it is in fact the case that control for the item onset is an inherently more salient marker for temporal tuning, it might be that performance was benefited more so in the onset control condition than in the offset control condition, explaining the results. Since this perceptual salience account may not adequately explain the observed transfer effects, this account should be further tested.

Similar to a perceptual salience account, an additional alternative explanation for the preliminary experiment results pertains to differences in attention capture. It may be the case that the visual onset of items served to capture attention during the counting task, as it has been shown to do in other situations (Yantis, 1993). Because the paradigm used in this task involved visual onsets in both conditions, an attention-capturing event would have occurred not only in the onset control condition, but in the offset control condition as well. The timing of this attention capture would have been different – and perhaps vitally so – between the control conditions, with capture occurring during the assimilate stage of the counting cycle while controlling item onset and likely during the consolidate stage while controlling item offset. Being the case, attention capture caused by the onset of next items during the offset control condition would have potentially lead to disruptions in consolidation, and thus a detrimental effect on counting in this condition.

Although the findings of the preliminary experiments seem to suggest an influential effect of control representation on performance during event counting (and perhaps during other routine tasks), the alternative explanations cannot be definitively ruled out using the results of the preliminary experiments alone. The following three thesis experiments were thus designed to continue examining this topic.

Chapter 5. Thesis Experiment Overview

Following from the preliminary findings, a series of three experiments was conducted to further explore the parameters by which various forms of control for event counting might influence performance and success at error monitoring. Experiment 1 was designed to determine whether the assimilate stage control effects observed in the preliminary experiments could be observed in a paradigm that limited some of the accounts of the original findings. The experiment was also used to determine the influence of internal and external criteria in the compare stage of the counting cycle. The aim of Experiment 2 was then to examine how the immediacy of control for external events in the assimilate stage might influence performance by means of support for temporal synchronization. Of primary interest was whether any beneficial effects of external event control might become diminished in situations where controlled events occur at a temporal distance from the actions used to evoke them. Experiment 3 then tested the importance of action-event consistency in determining the effect strength of event control.

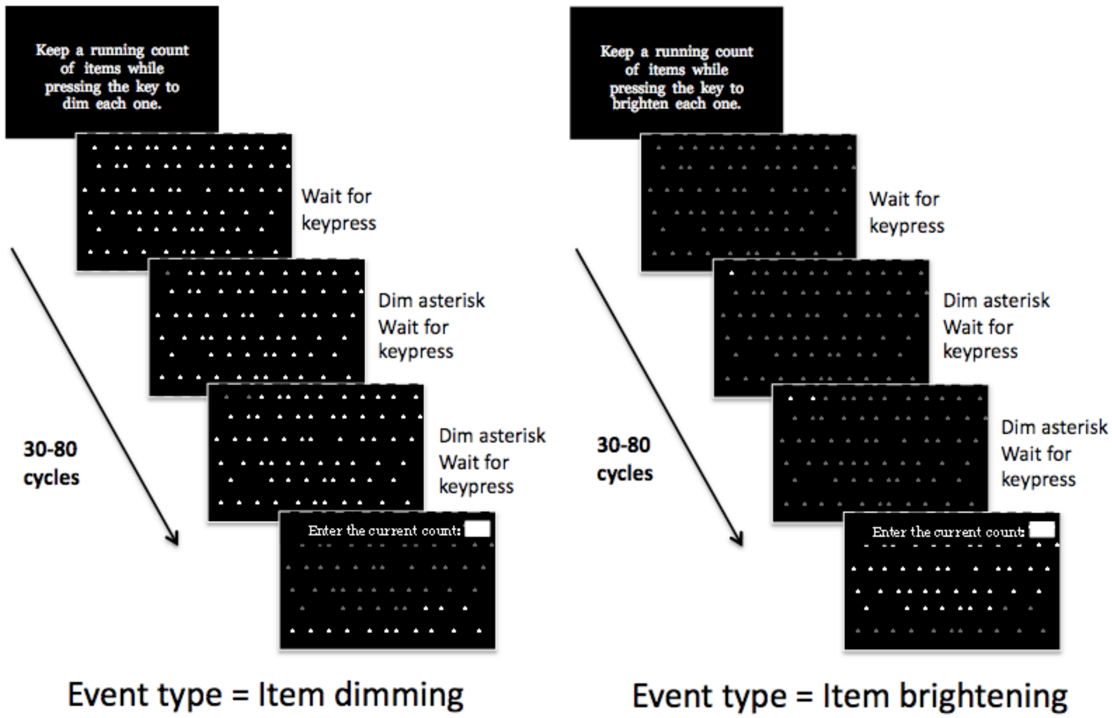

Figure 5.1: Thesis experiment task schematic. Keypress actions were used to either dim or brighten individual items in an array while counting.

An array counting paradigm (see Figure 5.1) took the place of the paradigm used in the preliminary experiments so as to address more specific questions about the parameters of external control representation and to provide a more balanced method for visually presenting items during the counting task. During the preliminary experiments, in order to equalize the amount of time taken by the computer to conduct its role in the counting cycle, the computer would render the designated effect of a keypress for 250 ms in both the onset and offset control conditions. In the *onset* control condition, the computer produced the appearance of an asterisk for 250 ms and then cleared the asterisk in preparation for the next keypress. In the *offset* control condition, the computer first cleared the asterisk to show a blank screen for 250 ms and then displayed the next asterisk in preparation for a following keypress. This method allowed for experimental balancing of the keypress effect duration (250 ms), but incidentally resulted in an unbalanced duration of asterisk appearances on the screen in the two conditions. Asterisks consistently appeared for 250 ms of the onset condition's counting cycle, yet appeared for variable durations in the offset condition's counting cycle because of a dependence on participant keypresses to clear them. To avoid this kind of presentational imbalance and to control for other potential perceptual confounds, the next experiments used a modified version of the counting paradigm, which displayed asterisks as the individual items in a spatially static array. Self-paced events were presented as changes to individual array items that would affect the luminance of an item but not clear the item from the screen.

Chapter 6. Thesis Experiment 1

In the preliminary experiments, which used a single-item sequential display counting paradigm, control for the immediate onset of counted items was more beneficial to performance than control for their immediate offset. To narrow down the possible accounts of these results, the current experiments used an array paradigm that eliminated the need for each participant action to be followed by both an item event and the necessary reversal of that event in preparation for the next step. In doing this, participant actions could be more definitively mapped to distinctly resulting events. Instead of item onsetting and offsetting events, item brightening and dimming were used as their intended analogues so that the new paradigm's spatially static array would not appear to grow and shrink as the effect of counting. The new spatial array paradigm thus made it possible to explore whether the assimilate stage control effects found previously are most accurately explained by a representational difference account or a more stimulus-driven perceptual salience or attention capture account.

In a second manipulation, instructions pertaining to the task goal directed participants to count array items until a certain goal criterion was satisfied. Participants either counted events until a visual prompt signaled them to stop (the *external* criterion condition) or until an assigned target number was reached (the *internal* criterion condition). Both the aforementioned assimilate stage manipulation and this new compare stage manipulation were implemented together in a between-subjects factorial design meant to assess their individual contributions to performance as well as their interactive effects. Interactions of the two control factors could suggest an optimal combination of event counting control factors for more successful performance.

In sum, the aims of the first experiment were threefold – 1) to determine whether similar assimilate stage effects to those of the preliminary experiments would be observed in a revised spatial array counting paradigm; 2) to determine whether differences in the compare stage criterion for counting could influence performance and metacognition for errors; and 3) to investigate interactive effects of control in the assimilate and compare stages.

6.1 Hypotheses and Predictions

6.1.1 Accuracy

Assuming that the event type manipulation of brightening/dimming is sufficiently analogous to the preliminary experiment manipulation of onsetting/offsetting items, it was expected that counting while controlling the brightening of items would lead to better accuracy than while controlling the dimming of items. Such findings would then provide evidence for discrediting an exclusive attention capture account of the preliminary experiment results, and instead suggest that the findings are best explained by either a representational or perceptual salience account.

It was also expected that counting toward the occurrence of an external signal would result in better accuracy than counting toward the satisfaction of an internal criterion (target number). Additionally, it was expected that the accuracy benefit of brightening items in the assimilate stage would be lessened when counting to a target number due to the likelihood of lowered engagement with, or attention to, the external environment.

6.1.2 Counting Rate and Fluency

Monitoring the external environment for a signal in the external criterion condition was expected to slow counting rate, lessen performance fluency, and increase cognitive demands, relative to performance of the internal criterion condition. These effects were predicted to arise out of a need to lessen the risk of counting past the unpredictable signal occurrence. In contrast, holding an internal target number as the intended goal criterion was expected to allow more rapid and fluent performance, owing to a more determinable goal state representation. It is worth noting that these hypotheses imply an assumption that the cognitive demands on attention for environment monitoring would outweigh the demands required to hold and compare current counts against an additional number in working memory.

6.1.3 Metacognition for Errors

By promoting slower, more deliberate processing and monitoring in order to avoid counting past a stop signal, performance in the external criterion condition (the signal case) was expected to be more explicitly and effectively monitored. More *implicit* performance monitoring anticipated in the internal criterion condition was expected to make detecting confusion errors difficult and thus make error monitoring less effective.

6.2 Method

6.2.1 Participants

One hundred and fifty students in introductory psychology courses at the Pennsylvania State University participated in exchange for a small amount of course credit. Half were assigned to a count-to-signal condition and the remaining half to a count-to-target condition Within these two groups, half controlled the brightening of items while the other half controlled the dimming of items, resulting in the four between-subjects groups of a 2 (criterion) by 2 (event type) factorial design.

6.2.2 Materials

All versions of the experiment ran on Windows-based personal computers controlled by E-Prime, version 1.1 software. Instructions and stimuli appeared on CRT monitors and participant responses were collected via standard computer keyboards

6.2.3 Task and Procedure

The experimental setup of all the three experiments mirrored that of the preliminary experiments, with participants seated at a computer in a small room lit by a desk lamp. Computerized instructions either instructed participants to count items in an array on the screen until they saw a prompt to stop, or until a pre-specified target number was reached. Instructions also indicated that participants were to control the pace of counting by pressing a key labeled “*” on the computer’s keyboard (the “P” key relabeled with an adhesive sticker) for each item as it is counted. They were informed that pressing this key would cause items to either brighten or dim as they go.

In addition to pressing the “*” key for each item as it was counted, participants were required to continually depress a key labeled “HOLD” (the keyboard’s “Q” key relabeled using an adhesive sticker) with the index finger of their left hand for the duration of each trial. This was required so that both hands would be needed to perform the task and could therefore not be used to point to or touch items on the screen while counting in an attempt to aid performance. These common strategies have been previously demonstrated to benefit counting accuracy by externalizing working memory demands (Carlson, Avraamides, Cary, & Strasberg, 2007). Participants in the count-to-signal condition were alerted to stop counting with the appearance of a computer dialog box that prompted them to type the current count. Participants in the count-to-target condition were instead shown a randomly generated number between 30 and 80 at the start of each trial and instructed to count that specified number of array items. To signal the point at which the target number had been reached, they were to press a “STOP” key (the relabeled “L” key). These participants were also required to enter the current count in order to verify that the target number was correctly maintained in WM over the trial duration. If the entered number varied from the target number assigned at the start of the trial, that trial’s data would then be excluded from analyses, as it would be impossible to determine whether counting errors had occurred apart from the working memory failure associated with retaining the target number.

Once the current count was entered, participants were prompted to rate their confidence on a scale of 1 (low) to 5 (high) indicating how accurate they believe their counting to have been during the trial. Responses to this question were used to gauge metacognition of errors. Ratings of 5 following accurate performance and 1 following inaccurate performance would demonstrate the most accurate metacognition scenario.

Arrays consisted of 100 asterisks displayed in 18-point Courier New font, positioned in a misaligned grid pattern. The spacing between adjacent asterisks was randomly generated for each trial so that chunking and mathematical strategies would be discouraged during counting. Participants counted a randomly determined number of asterisks between 30 and 80 for each trial, and counting proceeded in a top-left to bottom-right fashion that was guided by the change in luminance of each asterisk At the conclusion of experiment, a message on the computer monitor thanked participants for their time, and an experimenter gave them a debriefing form that explained the purpose of the study.

6.2.4 Design

The independent variable *criterion*, defined as counting toward a *target* or a *signal*, was randomly assigned between subjects, as was the independent variable *event type,* defined as *brightening* or *dimming* asterisks. A complete between-groups factorial design was chosen in order to provide a relatively straightforward analysis of the effects of goal criterion and event type on performance and monitoring, without the necessary interpretation of transfer effects between conditions. While the topic of transferability is an important one, it is not the focus of the current project and is recommended for follow-up in future research. Each participant completed 40 trials of one of the four conditions: target-dim, target-brighten, signal-dim, or signal-brighten.

6.2.5 Analysis

Data analysis for comparing the two criterion and event type conditions paralleled that of the preliminary experiments. Mean accuracy and counting rates were computed for each participant as measures of performance, and mean ratings of confidence on correct and incorrect trials were calculated as a measure of metacognitive processing.

6.3 Results

Two of the 149 participants showed difficulty in adhering to task instructions and both were excluded from data analyses An additional eight participants' data were dropped from analyses for exceeding a z-transformed mean score of 2.58 on at least one of the dependent measures of performance. This same criterion was used to detect and eliminate outliers in Experiments 2 and 3, and all outlier data can be seen in Appendix A After excluding these 10 participants, the final numbers of participants assigned to each group were: 35 in the signal-brighten condition, 37 in the signal-dim condition, 36 in the target-brighten condition, and 35 in the target-dim condition.

The first two of the forty experiment trials were considered practice and were not included in performance analyses. Additional trials were excluded on the basis of a total count differing from the correct count by more than five. This criterion was used previously in an event counting experiment carried out by Carlson and Cassenti (2004), whose pilot research suggested that counting errors greater than five in this type of task occur most frequently as a result of mistakes made when entering an answer, or of lost activation for a count's tens digit in working memory. In the current experiment, 3.1% of trials were excluded from analyses on account of this criterion (31 trials in the signal-brighten group, 51 in the signal-dim group, 44 in the target-brighten group, and 40 in the target-dim group).

One final exclusion criterion was selectively applied to the target condition trials. Since participants in this condition were required to verify the given target number at the end of each trial, any trials on which the target number was not correctly verified were excluded from analyses. This resulted in the removal of 280 total trials (10.5% of the all target counting trials). There was no reliable difference in the total proportion of trials incorrectly verified by participants in the brightening and the dimming conditions $t\,(68) = -.79$, $p > .05$. Participants in both groups verified the target number incorrectly an average of 4 of the 38 trials.

6.3.1 Accuracy

Counting accuracy was generally high in this task (M = 89.7%, SE = .009). Correct counts were given on 91.2% of trials in the signal-brighten condition, 86.6% of trials in the signal-dim condition, 90.5% of trials in the target-brighten condition, and 90.3% of trials in the target-dim condition (shown in Figure 6.1). There were no reliable effects of the event type or criterion manipulations, nor was there a significant interaction between the two, all $p > .05$.

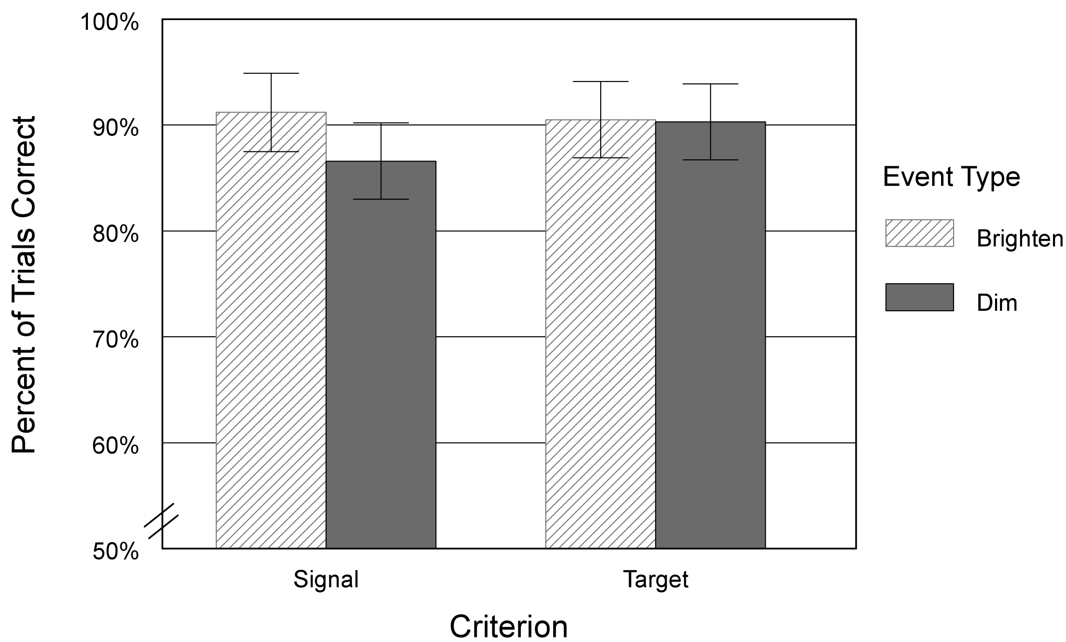

Figure 6.1: Accuracy results of Experiment 1 showing the percent of trials in which counting was correct in each of the four participant groups.

6.3.2 Signed Error

Among trials with error magnitudes between 0 and 5, the overall mean signed error was -.013, and neither the effects of event type or criterion, nor their interaction were significant, all $p > .05$. The majority of counting errors on incorrect trials (those with error magnitudes between 1 and 5) varied only slightly from the correct count. Visual inspection of the error frequency distributions (shown in Figure 6.2) suggested possible group differences in the occurrence of negative versus positive errors, and thus nonparametric tests were conducted to address this possibility.

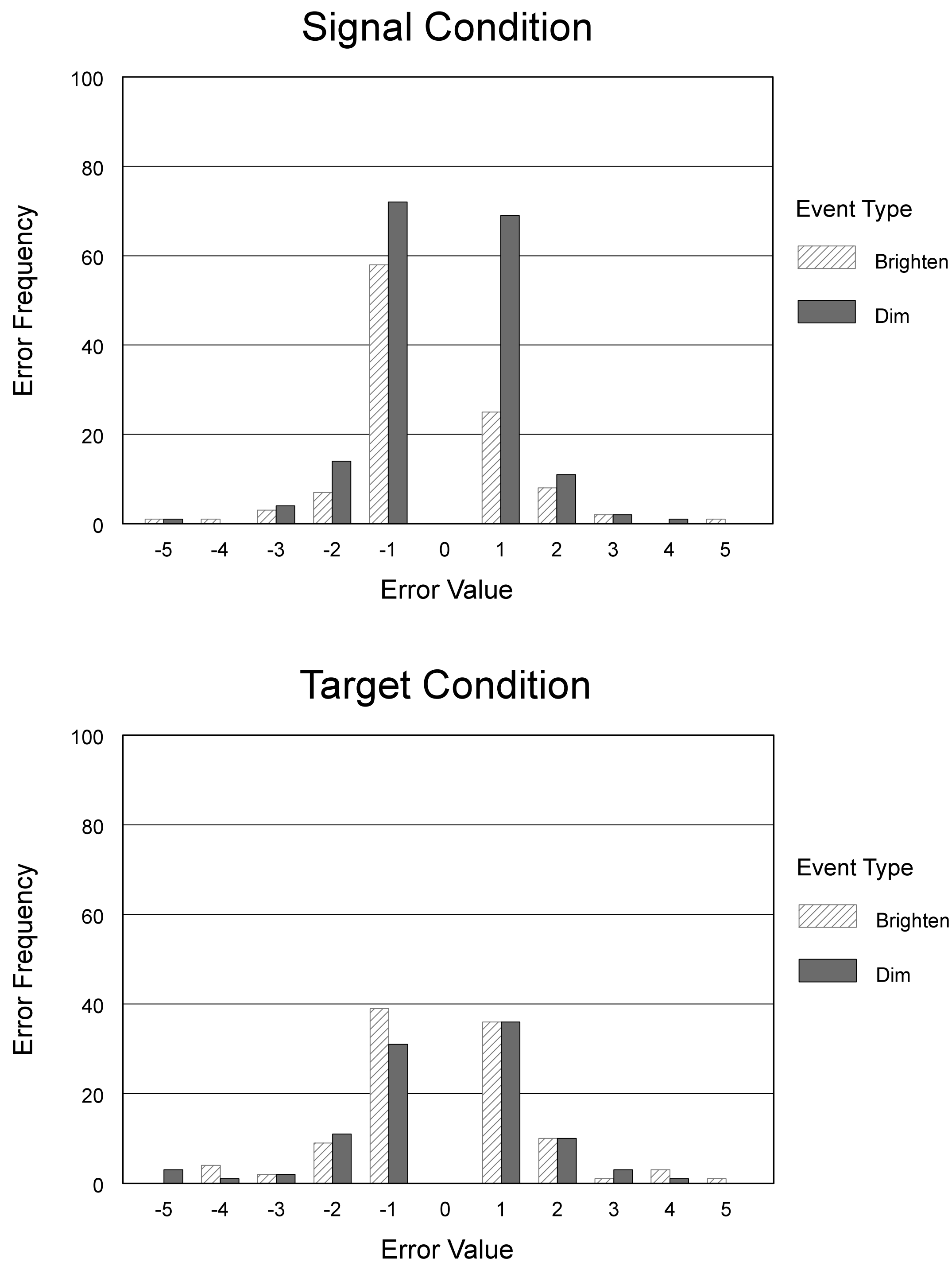

Figure 6.2: Experiment 1 distribution of incorrect trial errors valued -5 to 5.

Chi-square (χ^2) analyses on each of the four participant groups revealed that errors were in fact distributed symmetrically around zero in all but the signal-brighten case. Errors in this group were almost twice as often negative in direction than positive, indicating a propensity for undercounting in the signal-brighten condition, $\chi^2(1) = 11.09$, $p < .01$. Analyzing the frequencies of negative and positive errors showed a main effect of criterion on negative error frequency, $F(1, 60) = 3.85$, $p < .05$. This effect reflected that, on average, participants in the signal counting conditions committed more negative errors (*M* = 3.73, *SE* = .47) than participants in the target counting conditions (*M* = 2.38, *SE* = .50). In contrast, there were no reliable differences in the average frequency of positive errors, $p > .05$ (overall *M* = 2.78, *SE* = .28).

6.3.3 Absolute Error

An ANOVA performed on the magnitude of incorrect counts showed the absolute error being significantly greater in the target counting conditions (*M* = 1.49, *SE* = .06) relative to the signal conditions (*M* = 1.29, *SE* = .05), $F(1, 479) = 6.84$, $p < .01$ (see Figure 6.3). Combined with the error frequency data previously described, this would imply that although counting to a target number did not result in an increased number of inaccurate counts, it did result in greater magnitude errors than those made in the signal conditions.

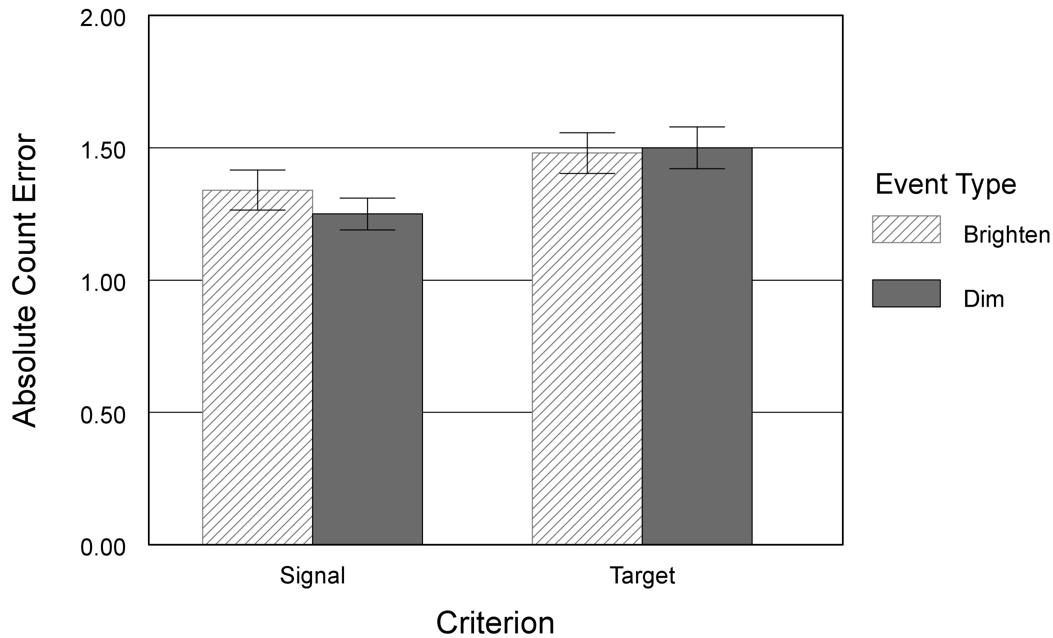

Figure 6.3: Average error magnitude on incorrect trials produced by participants in each of the four experimental groups of Experiment 1.

6.3.4 Counting Rate

Each participant's rate of counting for a given trial was calculated as the average cycle time per step – or the time between the onset of an array item (an individual asterisk) and the keypress to initiate the next item. The first four cycle times were excluded to allow for the pace of counting on each trial to stabilize. Because each trial contained a number of items randomly chosen between 30 and 80, the number of recorded data points for cycle time varied between 30 and 80 along with the number of items. Thus, each completed trial contributed at least 30 cycle times for analysis, but there were fewer cycle time data to analyze for later steps involved in longer counting sequences. For this reason, each trial's cycle time data on items 5 through 30 were used to calculate the overall mean cycle time.

On average, participants who counted to a target number performed at a rate of 346 milliseconds per item, while participants in the signal conditions counted at a reliably slower mean rate of 382 milliseconds per item, $F(1, 135) = 8.01$, $p < .01$. This average rate of counting falls within the expected range for subvocal counting, which is typically between 300 and 500 ms for normal adults (Wearden, 1991). The event type manipulation did not reliably differentiate group counting rate, nor did it interact with the criterion manipulation. With practice, counting rate became faster, as revealed by an analysis of the mean cycle time, for which trials were grouped by blocks of 10 (except for the first block, which included 8 non-practice trials), $F(1.98, 267) = 58.84$, $p < .01$ (see Figure 6.4). Within-subjects contrasts characterized the rate speedup as having linear ($F(1, 135) = 86.52$, $p < .01$) and quadratic trends ($F(1, 135) = 6.93$, $p < .01$). Parameter estimates more specifically described the main effect of criterion as having emerged during the second block of trials, then having continued to affect rate throughout the remainder of the experiment.

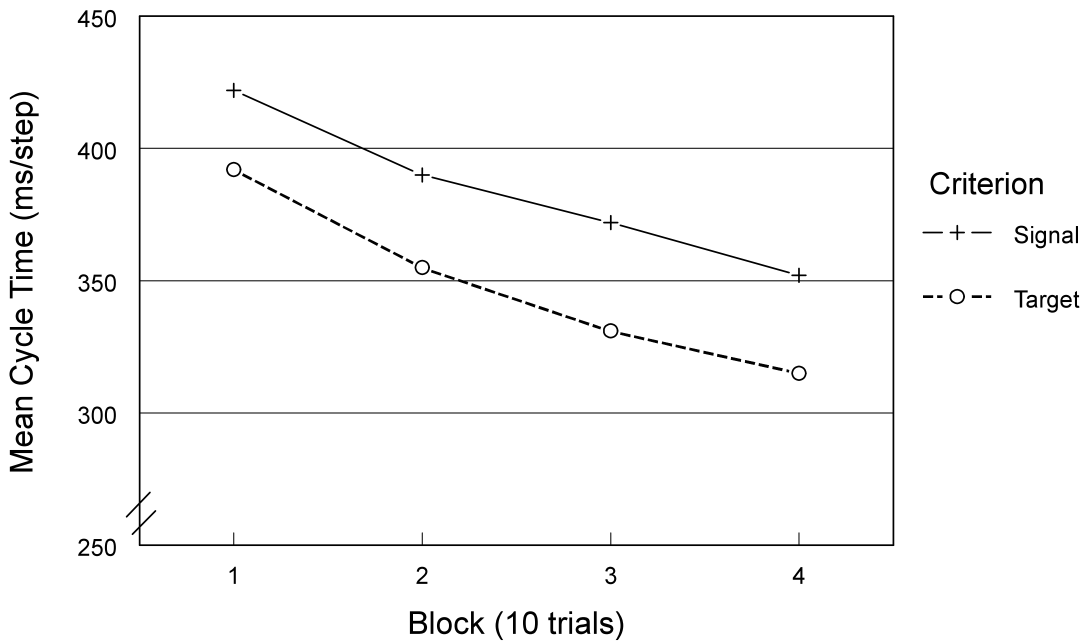

Figure 6.4: Mean cycle time to count one item in the array, displayed in milliseconds per step for Experiment 1.

A second ANOVA with a mixed factorial design of 4 (block: 1, 2, 3, 4) x 2 (criterion: signal, target) x 2 (event type: brighten, dim) was carried out on the mean cycle time coefficient of variation (ratio of standard deviations of intervals to mean interval) in order to examine counting rhythmicity. There were no reliable effects (all $p > .05$), and the overall mean coefficient of variation indicated that counting was approximately rhythmic ($M = .142$, $SE = .006$). For comparison, the rhythmicity of finger tapping in concert with an auditory rhythm, which might reflect a most-rhythmic case for this type of event counting task (Carlson & Cassenti, 2004), has a coefficient of variation around .04 to .05 (Wearden, 1991).

6.3.5 Metacognition for Errors

Ratings of confidence given at the end of trials were generally high, averaging 4.13 on the 1 to 5 scale in which a rating of 1 indicated a *complete guess* and 5 indicated *complete confidence*. Confidence was higher following accurate performance (accurate: $M = 4.52$, inaccurate: $M = 3.74$), and higher in the signal condition ($M = 4.31$, $SE = .09$) than in the target condition ($M = 3.95$, $SE = .08$), but both main effects were subsumed by their combined interaction, $F(1, 108) = 13.87$, $p < .01$ (see Figure 6.5). Parameter estimates revealed that the interaction between answer accuracy and the criterion manipulation was driven by a reliable difference in confidence on the incorrect trials, $t(56) = 2.59$, $p < .01$. There was no reliable effect of event type, nor was there an interaction between the criterion and event type manipulations, suggesting that brightening and dimming items did not influence the ability to detect counting errors. The subsequent test of the confidence difference scores restated this finding as a greater ability to discriminate between accurate and inaccurate performance in the target condition ($F(1, 108) = 13.87$, $p < .01$). The mean difference in confidence was 0.47 in the signal condition and 1.09 in the target condition.

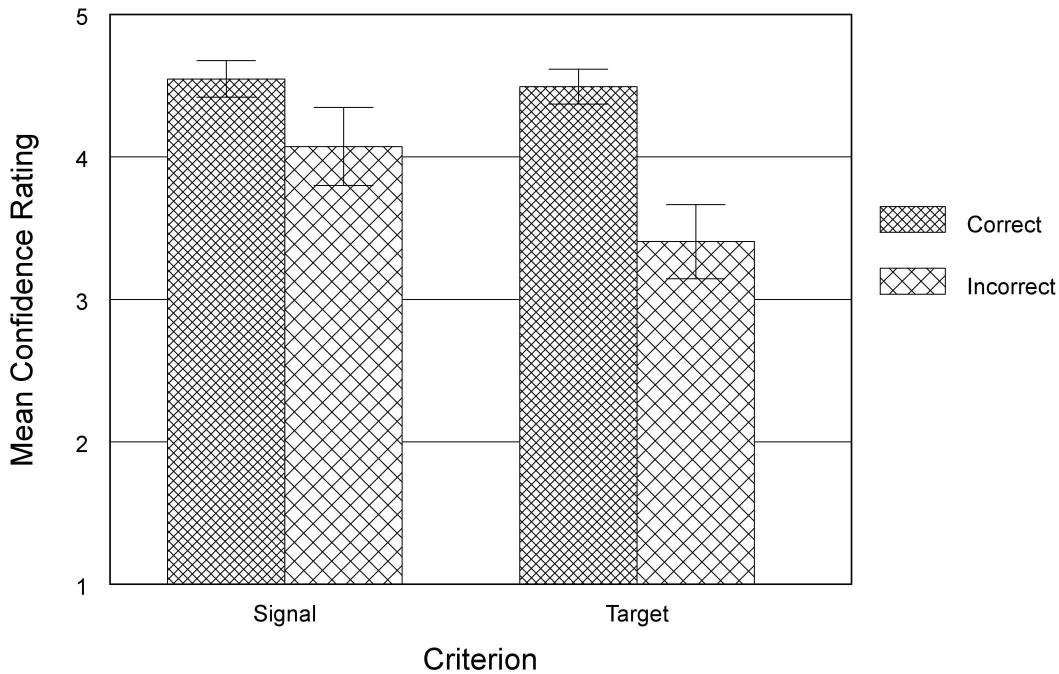

Figure 6.5: Mean confidence ratings following correct versus incorrect trial performance in Experiment 1's signal and target criterion conditions.

Error monitoring was also examined by categorizing confidence ratings as high (4-5) or low (1-3) and then comparing their relative frequency for correct versus incorrect trials. The plots of these data, shown in Figure 6.6, suggest that on the whole, participants were more likely to give an appropriately low confidence rating following inaccurate performance when they controlled item dimming instead of brightening.

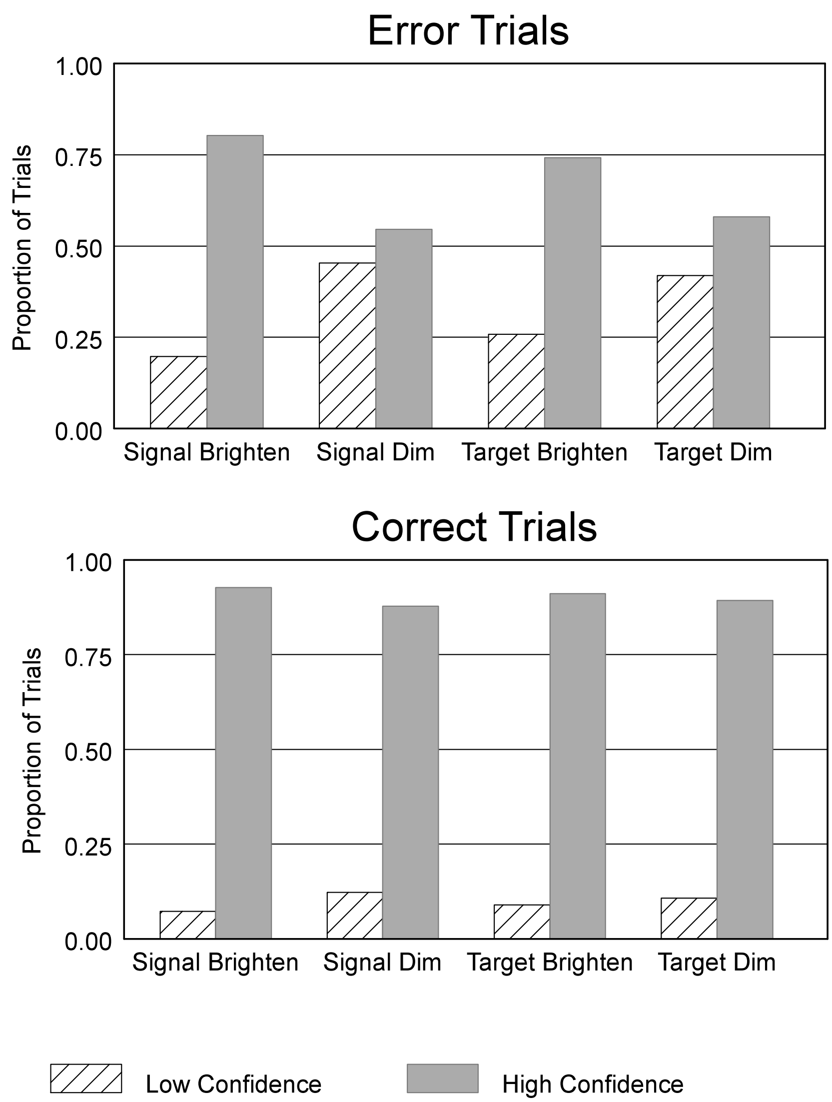

Figure 6.6: Experiment 1 confidence rating data displayed as the proportion of high versus low confidence ratings given after erroneous and correct performance (low confidence rating = 1-3; high confidence rating = 4-5).

6.4 Discussion

Experiment 1 failed to demonstrate the assimilate stage effect as clearly as expected using a brighten/dim manipulation of the spatial array paradigm. This fact suggests either that the brightening/dimming manipulation meant to be an analogue to the preliminary experiments' turning on/turning off manipulation was not sufficiently analogous, or that the revised array paradigm presented an exceedingly disparate task from that of the original single-item display paradigm. Seeing more cogency in this second possibility, it was surmised that the additional spatial information afforded by the array served the placekeeping function that had previously been accomplished in the single-item display paradigm by using event information to mark the counting cycle. Without needing the events to provide the same amount of timing and placekeeping information, there would be no preferential effect of one event type over the other. To explore this possibility, Experiment 2 examined whether the event type effects would arise in the array paradigm if a temporal delay separated actions from their resulting events and made it difficult to rely solely on spatial information.

In line with hypotheses regarding the compare stage of counting, performance was faster in the target criterion condition than in the signal condition, and errors were larger on average in the target condition. The effect of the goal criterion was also evident in the analysis of confidence ratings. Contrary to predictions however, error monitoring appeared to be better in the target, rather than the signal, counting condition. This might indicate that errors made while counting to a target number were more often a result of lapsed attention (i.e., loss-of-activation errors) or represented an accumulation of confusion errors over a trial, which might also be attributed to inattention (Reason, 1990). Either of these possibilities would help to explain why the target condition errors were both larger in magnitude and more detectable than those committed in the signal condition.

Chapter 7. Thesis Experiment 2

The purpose of the second experiment was to understand the role of temporal proximity on the influence of external event control during the assimilate stage of the event counting cycle. The temporal distance between controlling actions and their resulting external events (an item's changed state of appearance) was experimentally manipulated in order to assess the extent to which temporal distance might encourage the use of external events to mark the counting cycle and thus benefit performance. Prior to implementing the array counting paradigm in Experiment 1, immediacy was expected to best support performance and metacognitive monitoring. Once it was revealed that the event control manipulation did not significantly affect performance in the array counting paradigm, it was hypothesized that the controlled event type might only have a significant impact on performance when the need for added placekeeping arises. Temporal delays between one's actions and events were expected to increase this need for placekeeping in the array paradigm.

Three delay conditions were randomly assigned to experimental counting trials and it was hypothesized that the temporal delay of event control would linearly relate to the influential effects on performance and error monitoring, with shorter delays being the least influential. In one of the three delay conditions, events occurred after a delay of 100 ms following keypress actions. In a middelay condition, the action-to-change asynchrony was assigned as 300 ms; and in a long-delay condition, the asynchrony was yet a longer – 500 ms.

Results of the preliminary experiments suggest that the representation of one's external control (*what* action is being used to elicit *which* event) is likely to be determined by the form of control that elicits the most proximal event following a controlling action. This representational account of the effects of event control at the assimilate stage would therefore predict better performance in this second experiment with more immediate delay conditions (i.e., effects of control). However, the temporal tuning hypothesis (Carlson & Stevenson, 2002) would suggest that performance should be temporally adaptive at any delay length and thus generally unaffected by a delay in action effects if no other differences exist. In this case, if the representation of control does not have implications for performance, accuracy rates should be similar for all three delay conditions, or in fact *better* at longer delay conditions because of a need to incorporate event information in cycle marking.

7.1 Hypotheses and Predictions

Given the results of Experiment 1, the criterion manipulation was expected to influence counting rate, the magnitude of errors, and the ability to detect one's errors again in Experiment 2. In particular, counting was hypothesized to be faster when counting to a target, but at a potential cost of producing greater magnitude errors when counting was inaccurate. This scenario together with the previous findings also led to the hypothesis that error monitoring, as measured by confidence difference scores, would reflect better discrimination of performance in the target condition.

Prior to Experiment 1, a hypothesized inverse linear relationship between the assigned delay duration and resulting counting accuracy was expected to reflect the representational account of the event type effect. Since shorter delays between an action and a resulting event were assumed to increase the subjective feeling of event control in this task, it was also expected that their corresponding mental representations would be more specifically, or narrowly defined at shorter delays. Taking the findings of Experiment 1 into account however, evidence of an event type effect was expected to be greater in the longer delay conditions.

7.2 Method

7.2.1 Participants

One hundred and thirty students enrolled in introductory psychology courses at The Pennsylvania State University who had not participated in the first experiment took part in the experiment. Of those 130, three participants' data were not recorded due to a program error that prevented the data from saving to the computer at the end of the experiment.

7.2.2 Procedure

The experimental procedure was identical to that of Experiment 1, except that a delay interval between keypresses and events was added as a within-subjects manipulation. The delay remained consistent over a given trial, but varied on a trial-to-trial basis, with an equally probable, randomly chosen, duration of either 100, 300, or 500 milliseconds. This resulted in each participant completing 14 trials of each delay condition over a total of 42 experimental trials. In each delay condition, on each step the current array item changed from its initial state (either brightened or dimmed) to the opposite state following the participant's keypress plus the assigned delay of either 100, 300, or 500 ms.

7.2.3 Design

The delay condition varied within subjects. Each participant performed 42 trials, 14 in each delay condition. A new random sequence of delay conditions was selected for each participant. Participants were also randomly assigned to one of the criterion conditions and one of the event type conditions, resulting in the performance of one of the four between-subjects groups: signal-brighten, signal-dim, target-brighten, or target-dim.

7.3 Results

Of the 127 participants, data from 13 participants represented significant outliers on at least one dependent measure of the collective dataset and were thus dropped from analyses (refer to Appendix A). This left 25 participants assigned to the signal-brighten group, 27 to the signal-dim group, 31 to the target-brighten group, and 31 to the target-dim group.

Trial exclusion criteria followed that of Experiment 1. Trials with errors exceeding a magnitude of five accounted for 2.9% of the total trials. Of a total 144 errors greater than five, 32 were made by participants in the signal-brighten group, 52 by those in the signal-dim group, 24 by those in the target-brighten group, and 36 by those in the target-dim group.

In the target condition, 247 trials were excluded due to incorrectly verifying the target number at the end of a trial (9.96% of target counting trials overall). There was no reliable difference in the total proportion of trials incorrectly verified by participants in the brightening and the dimming conditions $t(60) = -.664$, $p > .05$. Participants in both groups verified the target number incorrectly an average of 4 of the 40 non-practice trials.

7.3.1 Accuracy

Counting accuracy was generally high overall ($M = 89.4\%$, $SE = .009$). A mixed design ANOVA (between-subjects factors: criterion & event type; within-subjects factor: delay) was used to examine the manipulation effects and interactions on counting accuracy. A main effect of criterion indicated that accuracy was higher in the target counting conditions ($M = 93.2\%$, $SE = .012$) than the signal counting conditions ($M = 85.5\%$, $SE = .013$), $F(1, 110) = 19.28$, $p < .01$ (see Figure 7.1). There were no other reliable effects on counting accuracy, all $p > .05$.

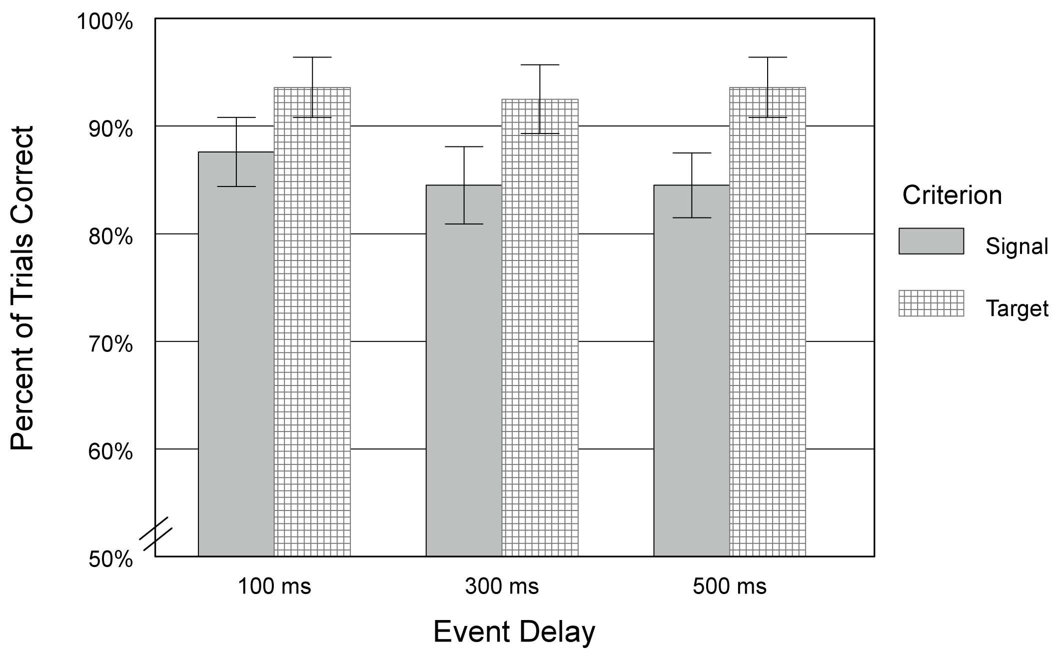

Figure 7.1: Accuracy results of Experiment 2 showing the percent of trials in which counting was accurate in the signal and target criterion conditions at each of the three event delays.

7.3.2 Signed Error

Among trials with error magnitudes between 0 and 5, the overall mean signed error was 0.019, and there was a reliable 3-way interaction of criterion x event type x delay, $F\,(2, 220) = 3.45$, $p < .05$. Contrasts indicated that the interaction expressed a reliable linear trend, $F\,(1, 110) = 4.26$, $p < .05$, which a plot of the signal condition data (see Figure 7.2) suggests was a shift toward greater overcounting with longer delays.

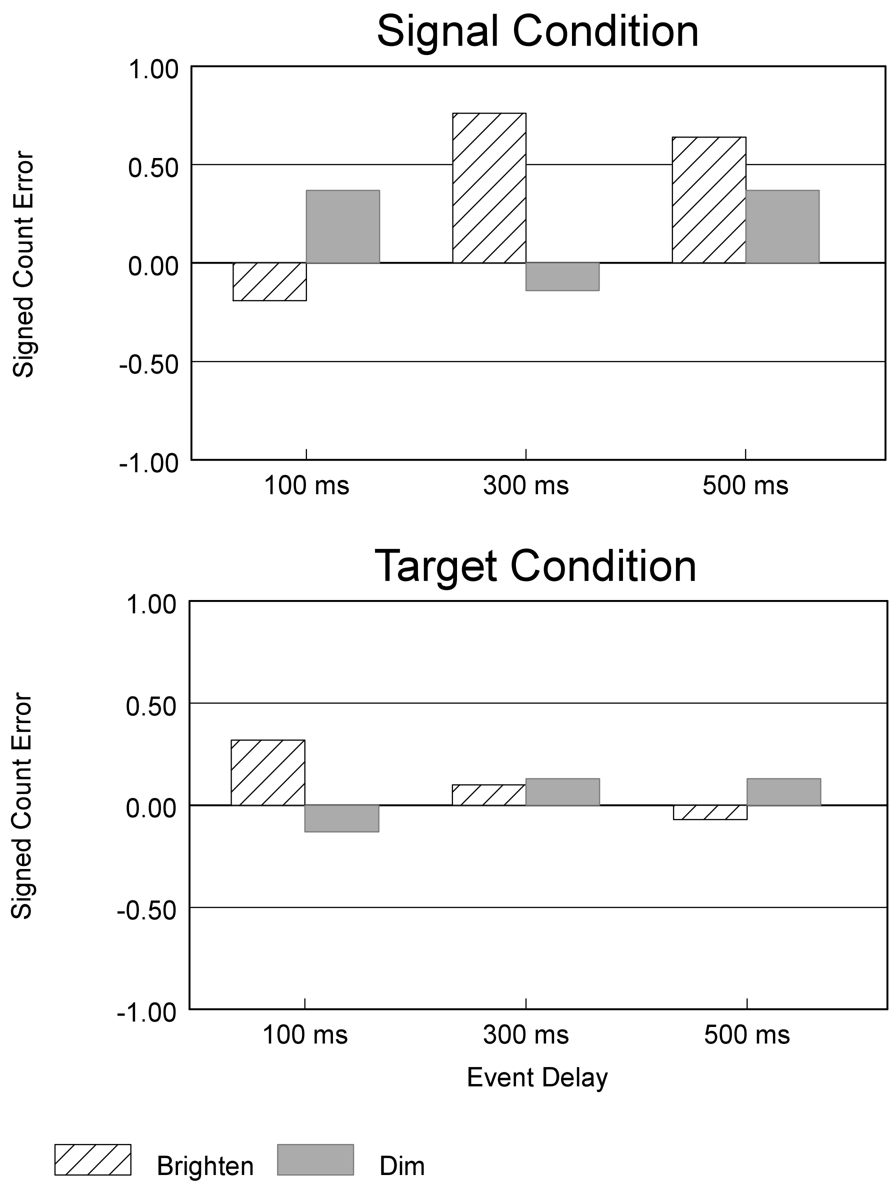

Figure 7.2: Mean signed error over all trials for each of the four participant groups, displayed by the trial event delay.

7.3.3 Absolute Error

A similarly designed ANOVA was performed on the average counting error magnitude and revealed a main effect of criterion, $F\,(1, 110) = 14.67$, $p < .01$ (see Figure 7.3). When counting to a signal, the average error magnitude was 0.19 (*SE* = .019). In contrast, the average error magnitude was 0.09 (*SE* = .017) when counting to a target number. The delay between actions and events did not reliably affect the average error magnitude, nor did it interact with other variables of interest, all $p > .05$.

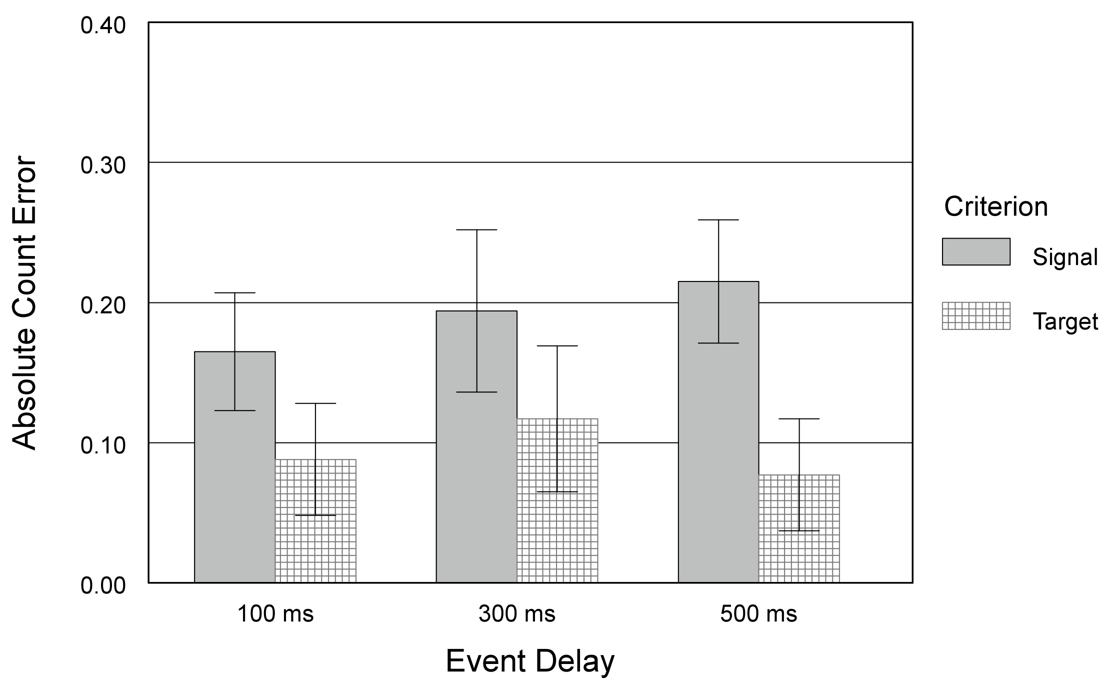

Figure 7.3: Mean absolute count error over all trials, displayed by each of the three event delay conditions performed by the two criterion participant groups.

7.3.4 Counting Rate

The analysis of counting rate examined the average response time between the occurrence of an event and a keypress intended to generate the next event (referred to here as the *request time)*. An ANOVA of the full experimental design revealed main effects of both the criterion, $F(1, 110) = 5.42$, $p < .05$, and event type manipulations, $F(1, 110) = 8.75$, $p < .01$ (see Figure 7.4). These effects were subsumed then by their interaction, $F(1, 110) = 4.98$, $p < .05$, which marginal means described as a large rate advantage for brightening relative to dimming events, but only when counting in the signal criterion condition.

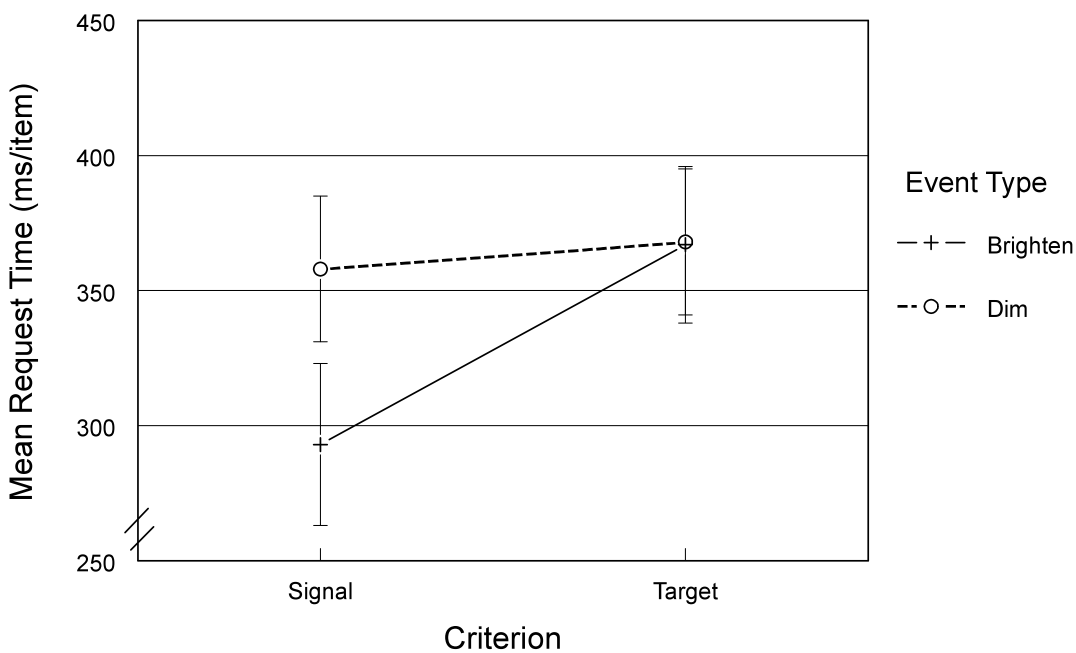

Figure 7.4: Mean item request times made by participants in each of the four experimental groups of Experiment 2.

The same analysis also described a reliable interaction between the delay manipulation and the event type manipulation, $F(1.7, 191.1) = 4.10$, $p < .05$. Planned contrasts described the delay manipulation in this effect as having a linear trend, $F(1, 110) = 5.10$, $p < .05$, which the plotted data illustrate in Figure 7.5. The plotted data demonstrate a slight item request time speedup in response to the longer event delays – which might reflect some compensation for the delay – but only when brightening array items.

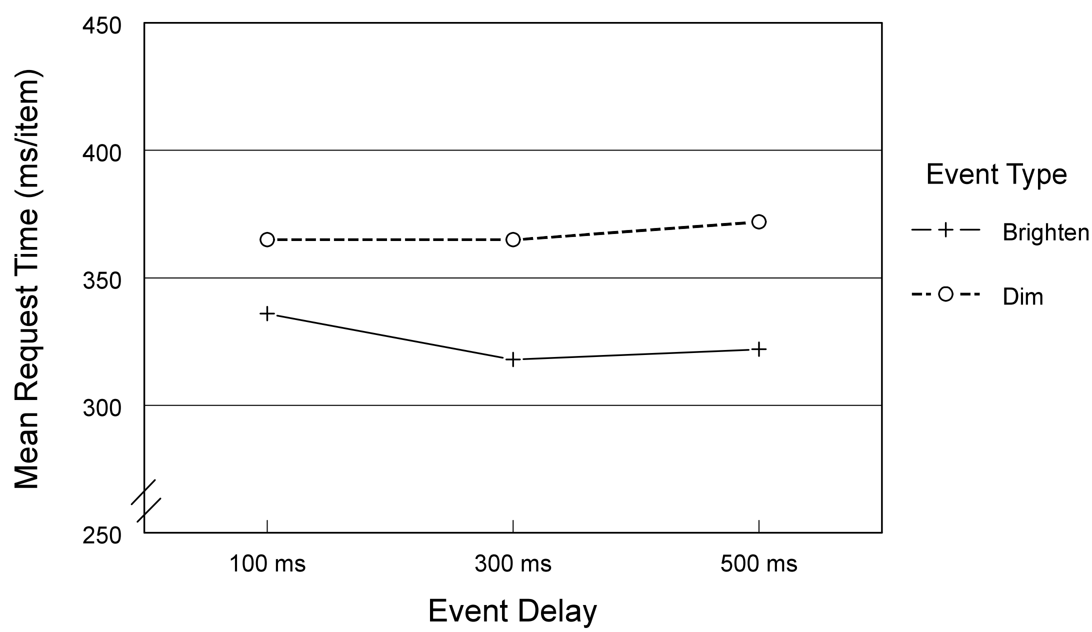

Figure 7.5: Mean item request times in Experiment 2, shown by the event type and event delay manipulations.

The total cycle times were also calculated so that the data could be plotted as a more accurate depiction of overall counting rate. Figure 7.6 shows the total cycle time calculated as the duration of the assigned delay condition plus the request time for a next item. The mean cycle times show little evidence of compensatory timing adjustments in response to the delay conditions. If the mean counting rates in Experiment 1 (signal = 382 ms/item; target = 346 ms/item) can be considered an accurate reflection of the groups' preferred counting rates, it is surprising that participants did not seem to adjust their mean request times in Experiment 2 such that counting could proceed at a more desirable pace. Since counting during a given trial could not proceed more quickly than at the pace of one item per assigned delay-duration (e.g., no faster than 300 ms per item in the 300 ms event delay condition), an optimal amount of temporal tuning would be reflected as an average cycle time approximating the lesser of 1) the assigned delay duration, or 2) the corresponding group counting rate seen in Experiment 1. In this sense, a complete adjustment in mean item request time for counting items in the 100 ms event delay condition would approximate 246 ms per item in the target condition and 282 ms per item in the signal condition. The adjustment of mean request time in the 300 ms event delay condition would approximate 46 ms/item and 82 ms/item for the target and signal conditions, respectively. In the 500 ms delay condition, however, an adjustment of item request time would near 0 ms/item and would result in an overall mean cycle time close to 500 ms/step, since this would be the fastest possible rate.

The lack of such findings in Experiment 2 might be an indication that the cost of repeatedly adjusting one's performance from trial to trial to account for a changed event delay outweighed the potential benefit of temporally tuning performance.

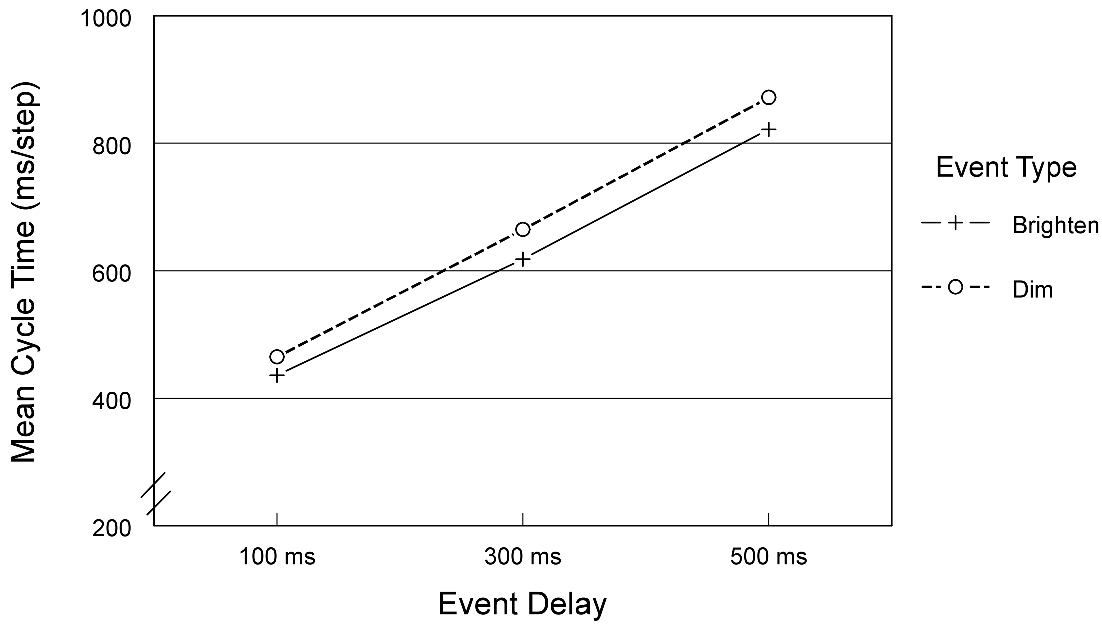

Figure 7.6: Mean cycle times reflecting the overall counting rate in Experiment 2.

7.3.5 Metacognition for Errors

Ratings of confidence were again high overall, averaging 4.17 on the 1 to 5 rating scale. A mixed-model ANOVA revealed a main effect of accuracy (F (1, 34) = 35.97, $p < .01$) as well as a marginal interaction between the event type and criterion manipulations (F (1, 34) = 3.36, $p = .076$ – see Figure 7.7). In the target condition, confidence appeared to be higher when items were brightened rather than dimmed, and a potential smaller and opposite trend appeared in the signal condition.

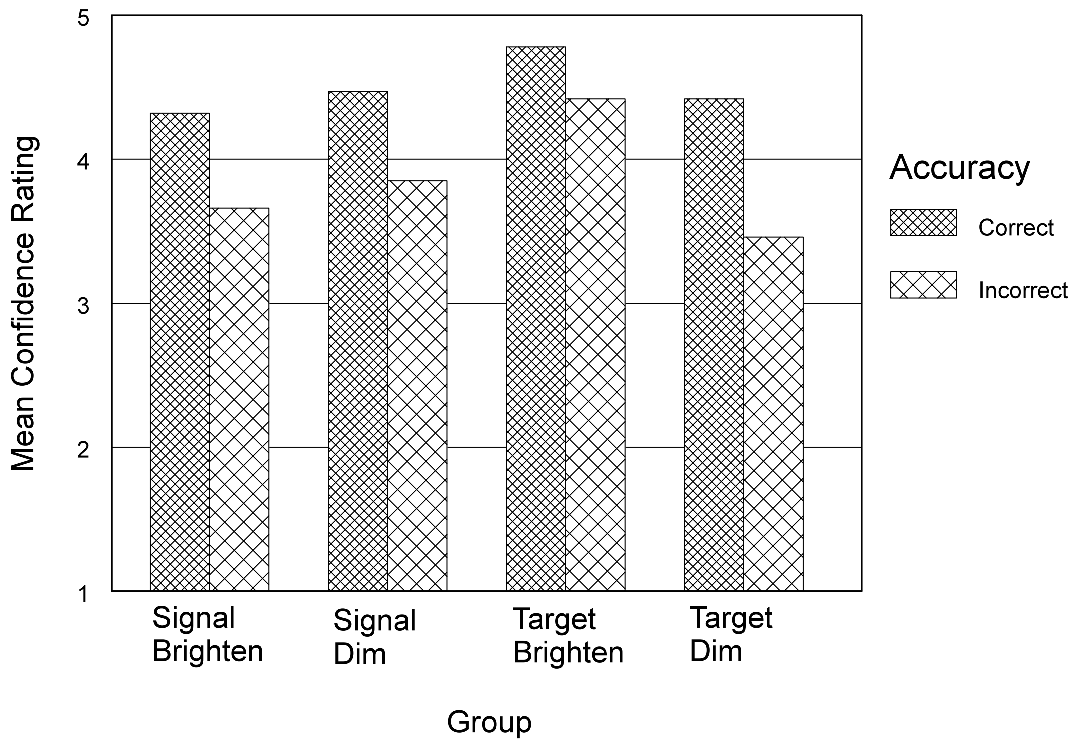

Figure 7.7: Mean confidence ratings for correct and incorrect trials in each participant group in Experiment 2.

Because the complex design of this experiment made it difficult to include all participant data in the analysis of variance, error monitoring was also examined by categorizing confidence ratings as low (1-3) or high (4-5) and then comparing their relative frequency for correct versus incorrect trials. The following series of figures (Figures 7.8 – 7.10) shows these data, but does not appear to uncover any additional findings.

100 ms

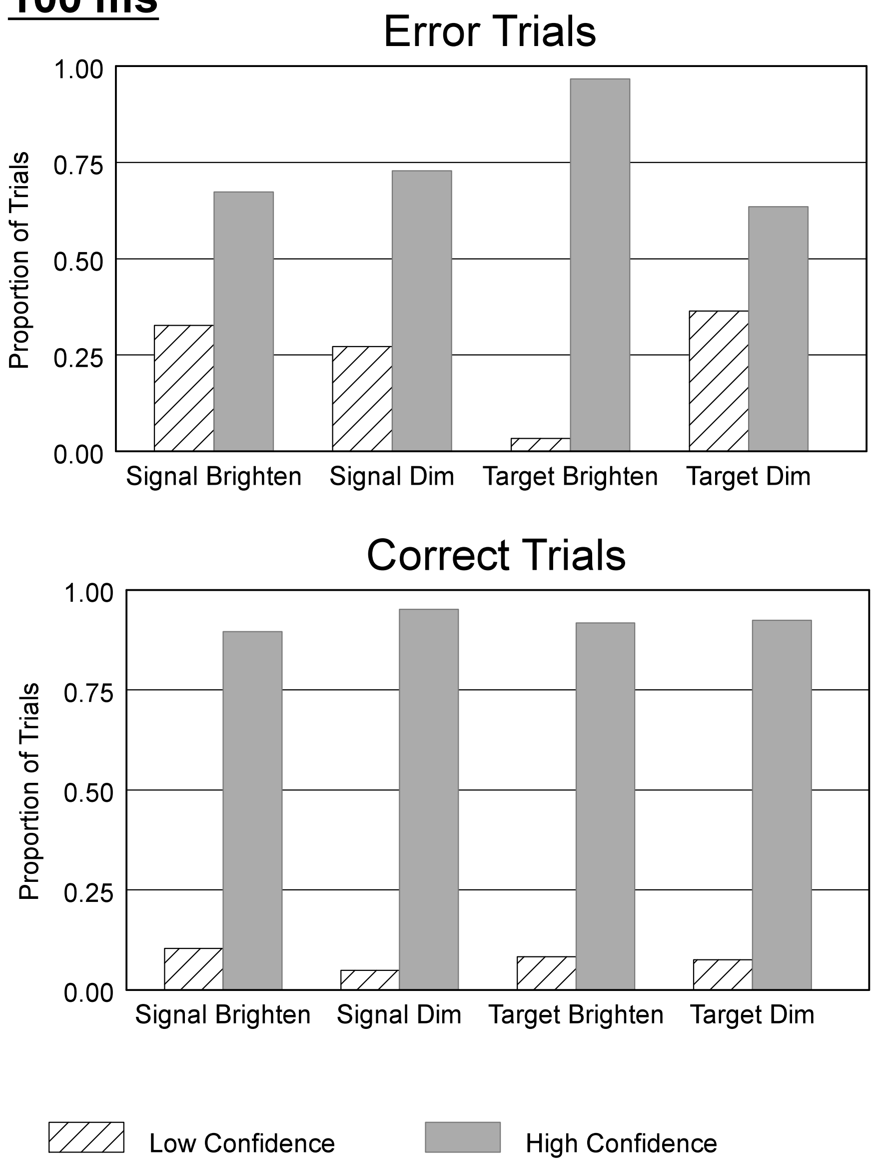

Figure 7.8: Proportion of error and correct trials in the 100 ms event delay condition of Experiment 2 that were rated with low (1-3) versus high (4-5) confidence.

300 ms

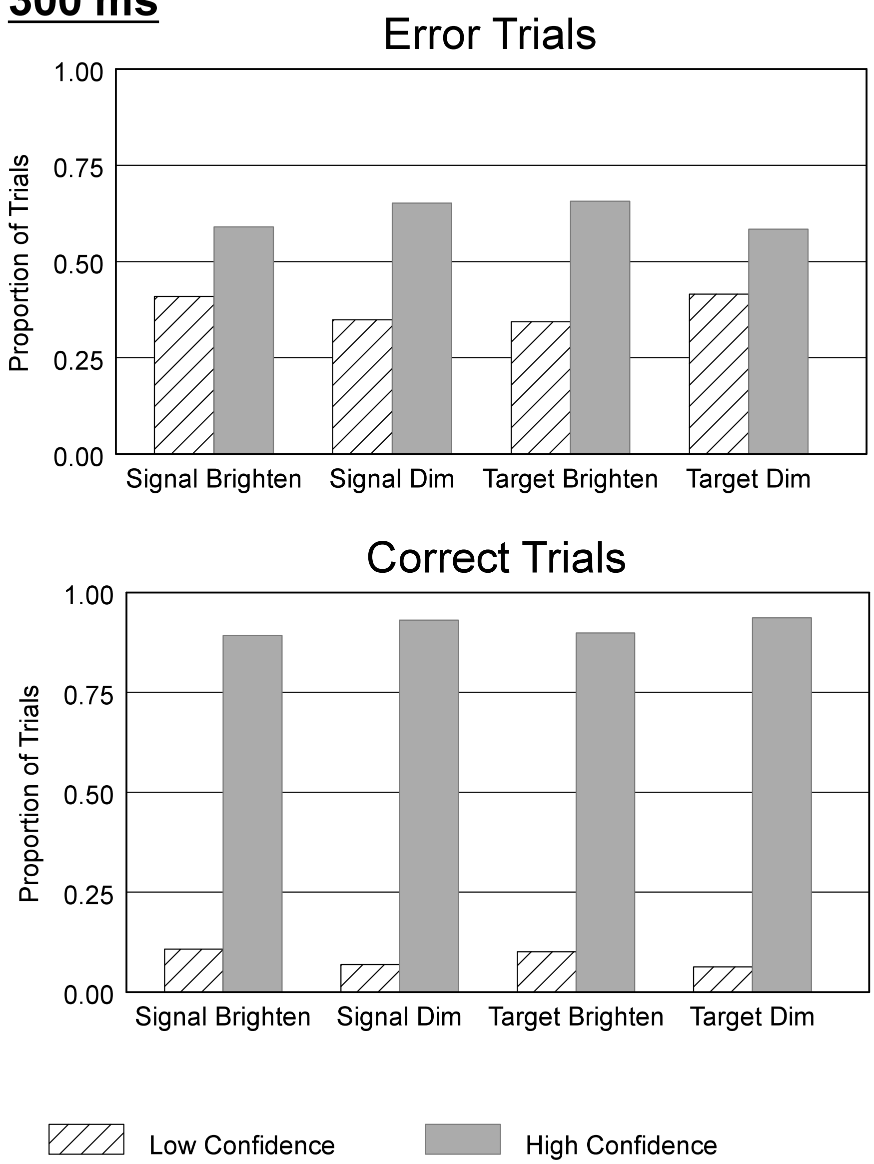

Figure 7.9: Proportion of error and correct trials in the 300 ms event delay condition of Experiment 2 that were rated with low (1-3) versus high (4-5) confidence.

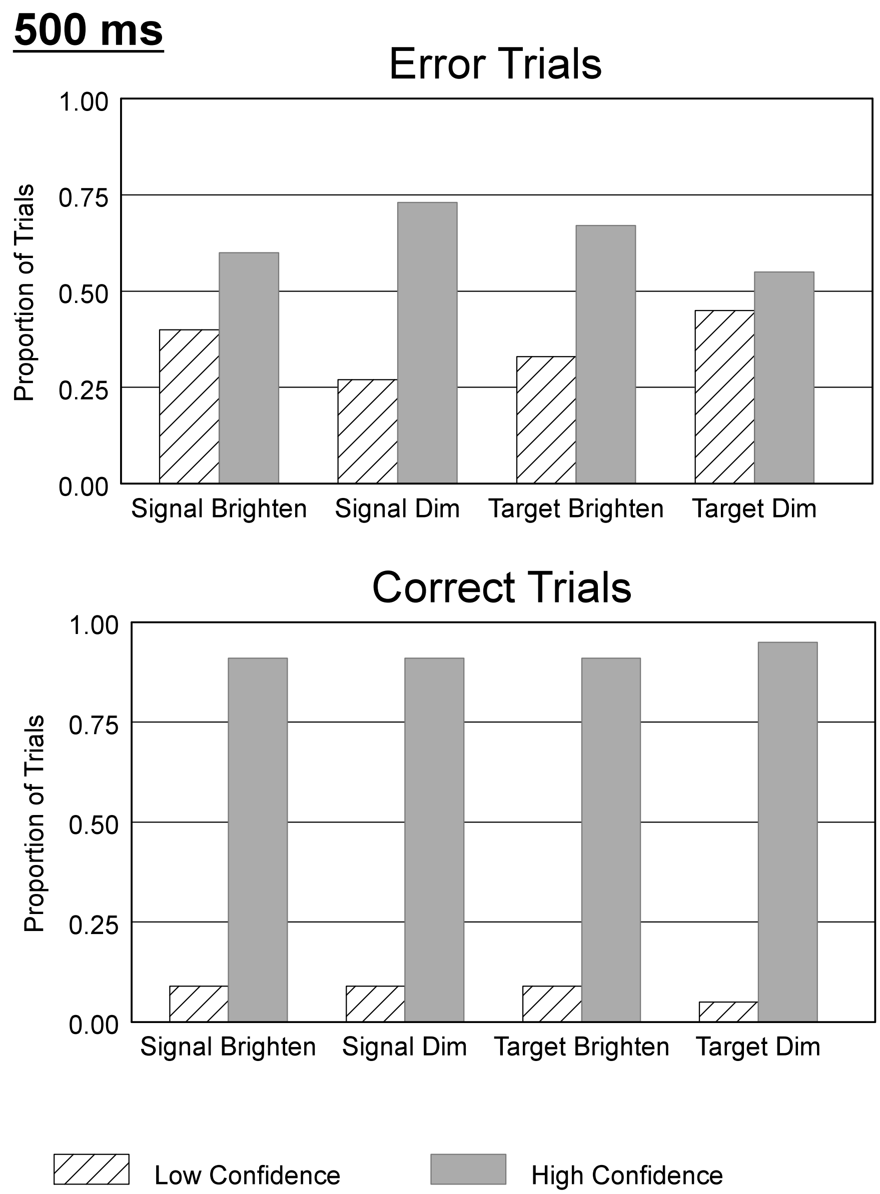

Figure 7.10: Proportion of error and correct trials in the 500 ms event delay condition of Experiment 2 that were rated with low (1-3) versus high (4-5) confidence.

7.4 Discussion

Results of this experiment provide evidence of both an assimilate stage and compare stage effect on performance in the array counting paradigm. Short of conclusiveness, much of the findings suggest that the type of event following one's actions affects performance more when attention to the environment is emphasized in anticipation of a stop signal. Similar to the findings in the preliminary experiments, the effect of event type while counting towards a stop signal revealed a performance benefit for item brightening, or *turning on,* relative to item dimming, or *turning off.* Adding this evidence sufficiently rules out an attention capture account of the preliminary experiments' findings. It remains unclear, however, whether the representational account or perceptual salience account of event type effects should best explain the findings.

Contrary to hypotheses concerning the nature of event control representations at differing temporal distances between actions and events, there was little evidence in Experiment 2 of the delay manipulation interacting with the effects of event type control. An unexpected lack of temporal tuning evidence, however, implies that participants were not using event information to mark the counting cycle and aid placekeeping efforts. It stands to reason that the complex design of the experiment and the trial-to-trial variability of the event delay may have made it difficult to reliably use an event for marking a point in the counting cycle, or to incorporate delay information into one's representation of event control. This may reflect the notion that performance efficiency depends largely on attaining uniformity over practice, and thus comes at a tradeoff with performance flexibility (Welford, 1976). In fact, it has been noted that mixed block designs, which assign the levels of a variable across trials, tend to slow the response to levels of that variable (i.e., result in *mixing costs*) and lessen the effects of the variable relative to its effects in a pure block design (Los, 1996). Thus, the lack of consistency in the delay of events and the task's demand for flexibility might account for the relative absence of efficient performance. Consequently, it is difficult to assess the relative contributions of an event's salience versus its control representation on performance in this task. In order to more successfully do so, Experiment 3 repeated this experiment using only the signal criterion condition, and implemented a fully between-subjects factorial assignment of the two event type conditions (brighten & dim) and two delay conditions (100 ms & 500 ms).

Chapter 8. Thesis Experiment 3

Without a clear picture of how temporality might influence the effects of event control, it remains to be determined whether the observed assimilate stage effects are a result of representational or perceptual salience influences. To help in differentiating the effects of these two possible accounts, the properties of event control (i.e., the timing and appearance of the event) were made to be completely consistent throughout the task in Experiment 3. A delay manipulation with two levels (100 ms & 500 ms) was assigned between groups, and, to enable a more straightforward interpretation of results, only the signal criterion case was used.

8.1 Hypotheses and Predictions

It was hypothesized that a consistent delay in events following one's actions would lead to a greater differentiation between the control representations for item dimming and item brightening. Additionally, this representational difference was expected to be more pronounced in the shorter event delay condition since preliminary experiment results suggested that more immediate events tended to be those represented as controlled. These hypotheses are also consistent with Duval & Duval's (1983) assertion that high temporal proximity and temporal covariation between effects and their possible causes increases one's tendency to attribute causality to those causes.

It was therefore expected that the shorter delay condition would lead to larger event type effects of item brightening versus item dimming than in the longer delay condition. An interaction showing the performance benefits of brightening over dimming as more pronounced in the 100 ms delay condition would support a representational account of the assimilate stage effects.

Alternatively, an interaction between the event type and event delay manipulations that illustrates a larger effect of the event type manipulation in the 500 ms event delay group would be more reflective of a perceptual-salience account of the event control effects. This account would purport that the occurrence of a highly salient, yet delayed, item brightening may be more jarring and disruptive to performance than the delayed occurrence of a less salient dimming event. In this case, brightening items in the 500 ms delay condition would likely result in counting performance that is less accurate, slower, and better monitored than performance in the item dimming condition.

8.2 Method

8.2.1 Participants

One hundred and twenty-seven students enrolled in introductory psychology courses at The Pennsylvania State University who had previously participated in Experiment 1 or 2 took part in the experiment.

8.2.2 Procedure

The same array counting task and experimental procedures that were used in Experiments 1 and 2 were implemented in Experiment 3. Participants counted either the controlled brightening or dimming of array items until a stop signal appeared on the computer monitor. One of two delay intervals – 100 ms or 500 ms – was assigned randomly between subjects and remained consistent throughout the task.

8.2.3 Design

The experiment used a between-subjects 2 (event type: brighten, dim) x 2 (event delay: 100 ms, 500 ms) factorial design, in which participants performed 42 trials of their assigned condition. Again, the first two trials were considered practice and were left out of analyses on performance.

8.3 Results

Out of 70 participants, 7 were excluded from analyses for producing data that exceeded the 2.58 z-transformed score threshold on at least one dependent measure (refer to Appendix A). This left a final: 16 participants in the brighten-100 ms group, 16 participants in the brighten-500 ms group, 14 participants in the dim-100 ms group, and 17 participants in the dim-500 ms group.

In this experiment, errors with magnitudes greater than five accounted for a total of 1.5% of trials, and these trials were excluded from statistical analyses.

Of a total 38 errors greater than five, 14 were made by participants in the brighten-100 ms group, 8 by those in the brighten-500 ms group, 5 by those in the dim-100 ms group, and 11 by those in the dim-500 ms group.

8.3.1 Accuracy

Overall counting accuracy was 85.8% in this task (*SE* = .015). There were no reliable effects of the two manipulations on counting accuracy, all $p > .05$.

8.3.2 Signed Error

Among trials with error magnitudes between 0 and 5, the overall mean signed error was 0.012, and there were main effects of both the event type ($F(1, 59) = 4.32$, $p < .05$) and event delay ($F(1, 59) = 6.52$, $p < .05$) – see Figure 8.1. The mean signed error was 0.049 in the brightening event conditions and -0.024 in the dimming event conditions. At the shorter delay, mean signed error was -0.032, while at the longer delay it was a positive 0.057. Taken together, results revealed the overall error direction as more positive (an indication of overcounting) when participants brightened the counted items and when the delay between actions and events was longer.

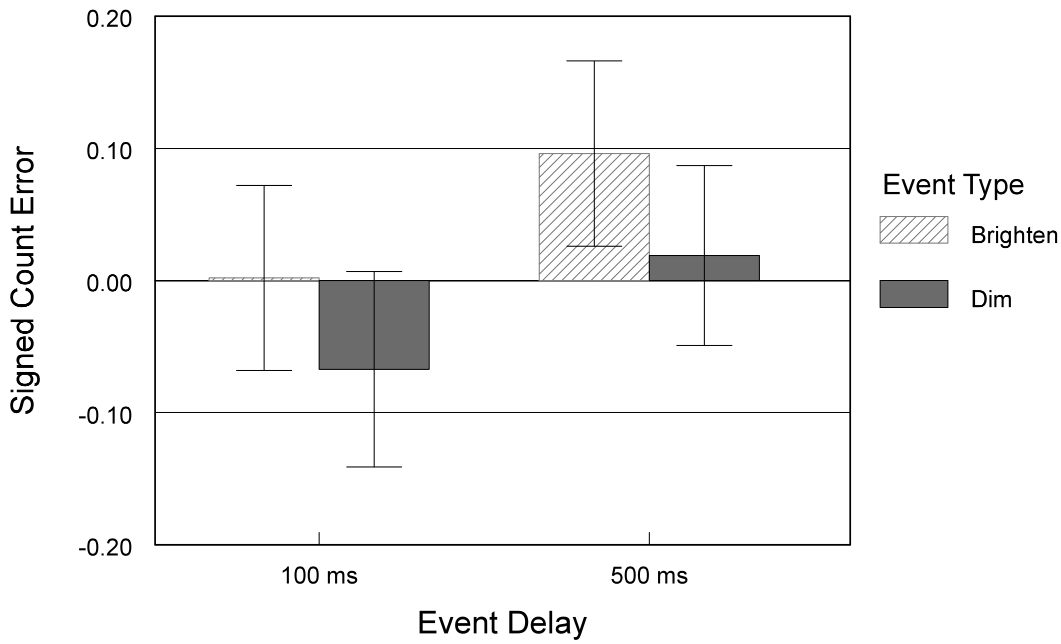

Figure 8.1: Mean signed error showing relative undercounting and overcounting between the two delay conditions and two event type conditions of Experiment 3.

8.3.3 Absolute Error

A between-subjects factorial ANOVA (2: event delay x 2: event type) was used to examine the manipulation effects on mean absolute error. A marginal main effect of delay (F (1, 59) = 3.53, p = .06) suggested that the overall magnitude of errors in this task was slightly greater when the delay between actions and events was longer (100 ms = .152; 500 ms = .242) – see Figure 8.2.

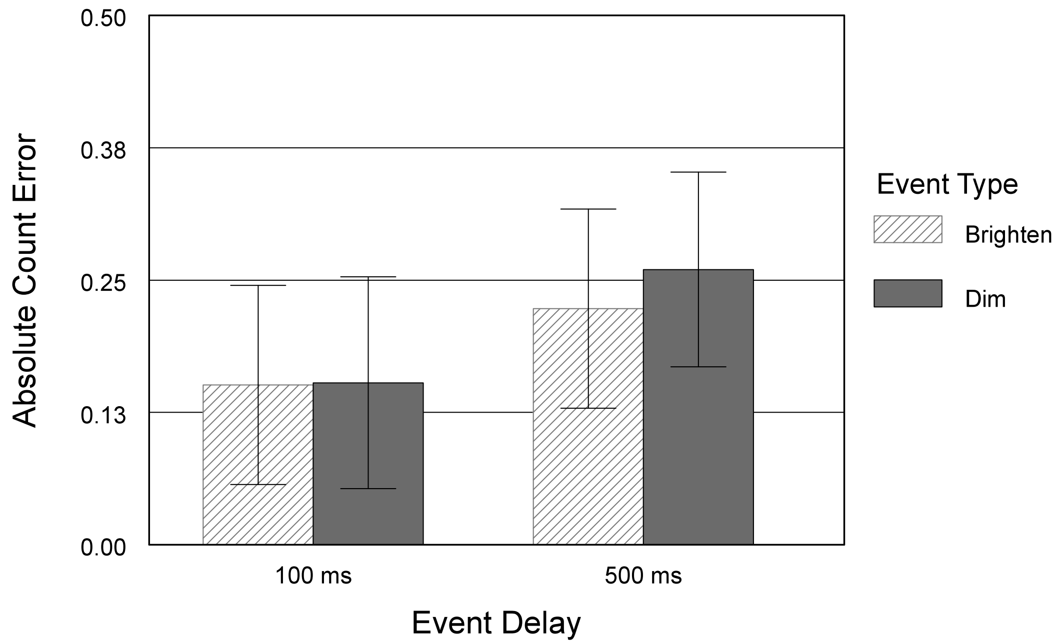

Figure 8.2: Overall mean absolute count error in Experiment 3 plotted by the two event type conditions and two event delay conditions.

8.3.4 Counting Rate

The analysis of counting rate examined the effects of the two manipulations on the average response time between an event and a following keypress intended to generate the next event. A between-subjects factorial ANOVA (2: event delay x 2: event type) revealed main effects of both the event delay (F (1, 59) = 4.03, $p < .05$) and the event type (F (1, 59) = 6.64, $p < .01$). Beyond these main effects was a reliable interaction between the delay and event type manipulations (F (1, 59) = 3.96, $p < .05$ – see Figure 8.3), which showed a pattern of slight temporal tuning to the delay in the dimming condition, but an absence of such tuning in the brightening condition.

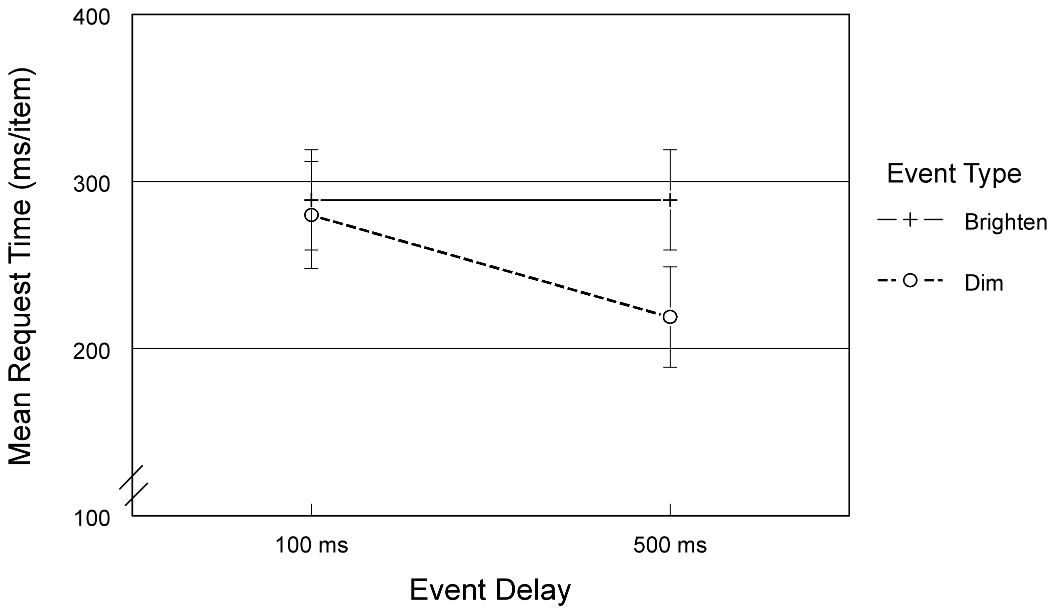

Figure 8.3: Mean item request times in Experiment 3, shown by the event type and event delay manipulations.

Figure 8.4 depicts the same data as a plot of the total mean cycle time in order to view the entire counting rate between the groups, and to more clearly view the suggested temporal tuning trend.

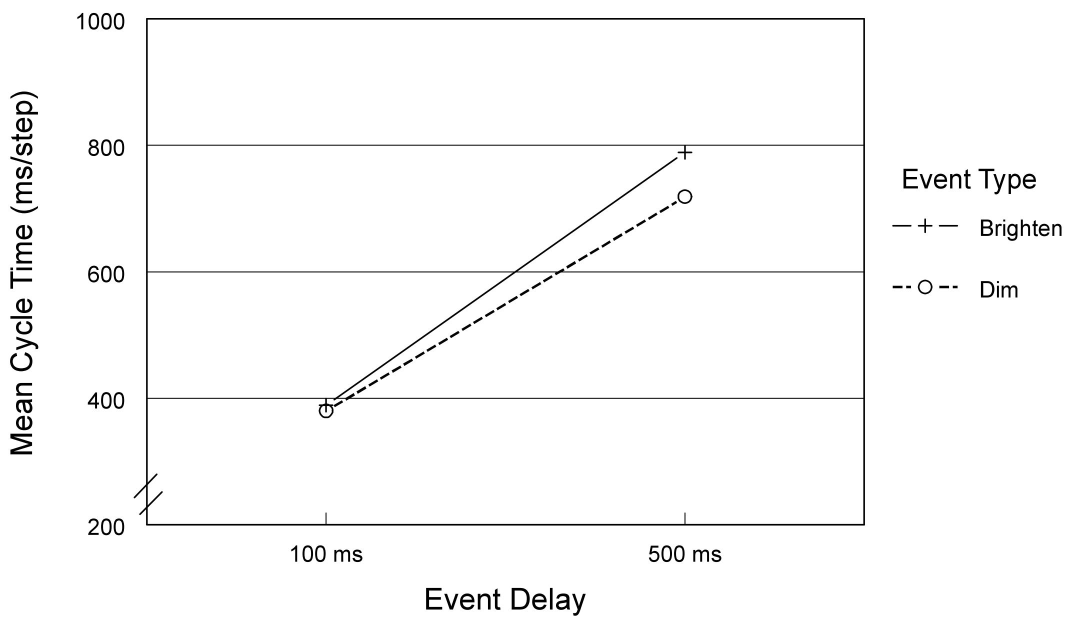

Figure 8.4: Mean cycle times reflecting the overall counting rate in Experiment 3.

8.3.5 Metacognition for Errors

Ratings of confidence given at the end of trials were high overall, averaging 4.37 on the 1 to 5 scale. Confidence was reliably higher following accurate performance (accurate: $M = 4.61$, inaccurate: $M = 4.13$), F (1, 53) = 58.87, $p < .01$. The average confidence rating was also higher in the 100 ms delay condition ($M = 4.51$, $SE = .10$) than in the 500 ms delay condition ($M = 4.23$, $SE = .09$), F (1, 53) = 4.11, $p < .05$ (see Figure 8.5). There was no reliable effect of event type, nor was there an interaction between the event type and delay manipulations in this task. Plotting data for the proportion of trials rated with high (4-5) versus low (1-3) confidence did not reveal any additional patterns in the error monitoring data (see Figure 8.6).

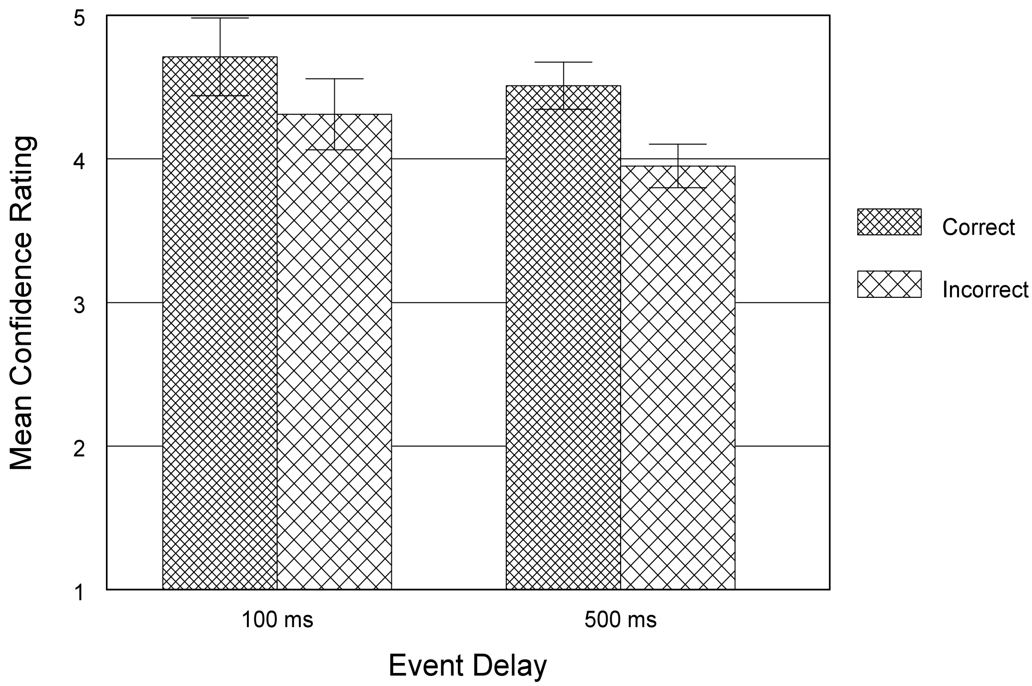

Figure 8.5: Mean confidence ratings for correct and incorrect trials in each event delay group of Experiment 3.

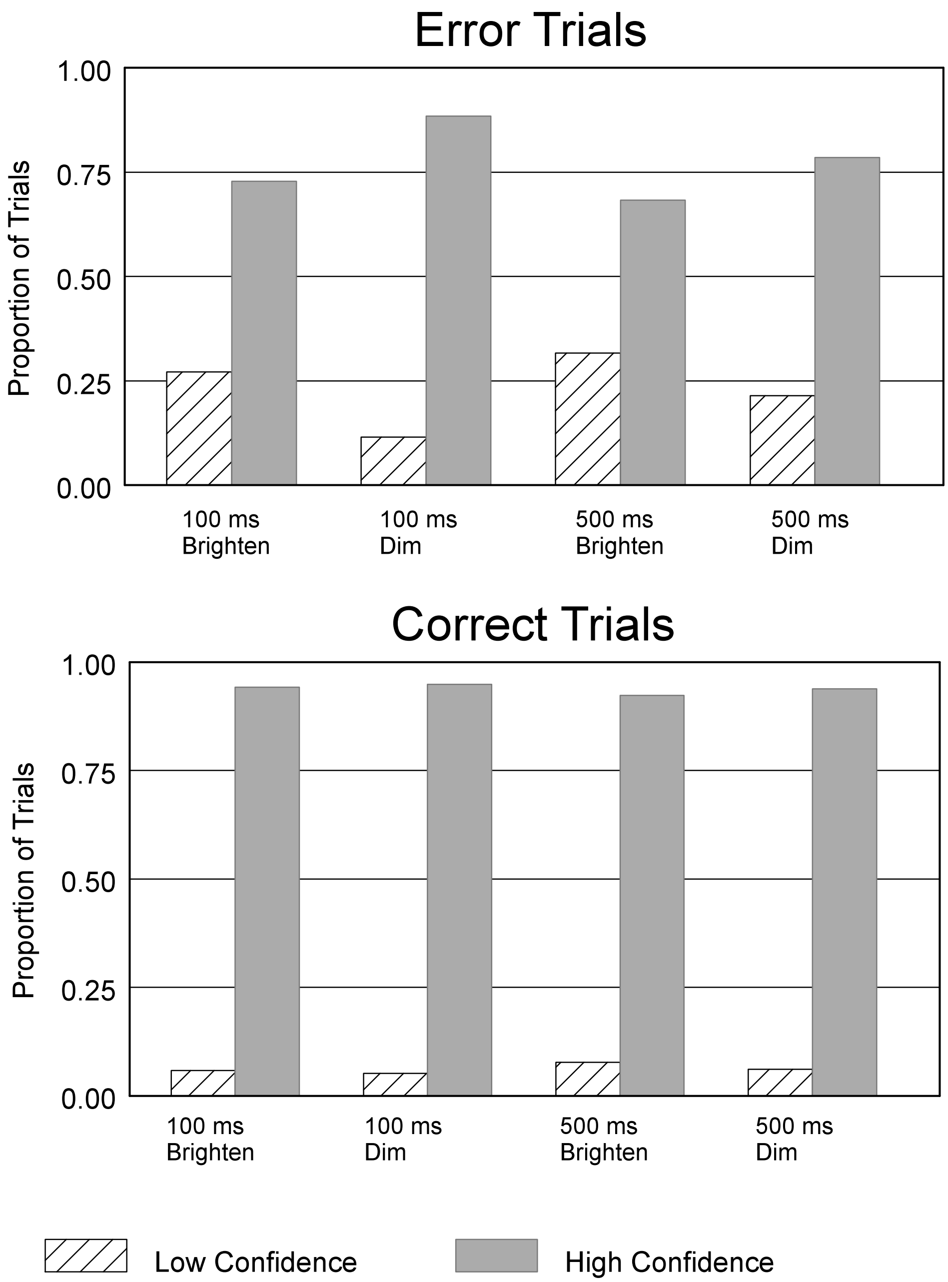

Figure 8.6: Proportion of error and correct trials in Experiment 3 that were rated with low (1-3) versus high (4-5) confidence.

8.4 Discussion

The effects of Experiment 3 provide little support for the hypothesis that event type effects on counting performance are the product of representational differences of control. None of the dependent measures illustrated pronounced effects of brightening over dimming at the shorter delay relative to the longer delay condition. Despite this, the data demonstrated that the longer delay condition had a negative impact on overall confidence, suggesting that temporal proximity may have in fact affected participants' subjective feelings of control irrespective of trial accuracy. In light of this, it seems unlikely that the representation of event control largely contributed to the previous assimilate stage effects. This is because the current experiment's confidence data suggest the influence of event delay on feelings of control, yet at the same time, there is no evidence that these feelings of heightened control in the shorter delay condition led to any positive impacts on performance that the representational account would predict.

This would leave the perceptual salience account as the one remaining, proposed explanation of event control effects. Short of sweeping conclusiveness, there did appear to be a consistent effect of the event type manipulation on performance speed when substantial delays separated controlling actions from their perceptual effects. This indicates that the perceptual salience account accurately predicted both 1) that the effects of the event type manipulation would be greater when there is a longer delay between actions and resulting events, and 2) that more salient events would lead to slower performance under longer delay conditions. The combined results of the experiments suggest then that although the immediate control of perceptually salient events might provide a beneficial means for coordinating performance and placekeeping, perceptual salience may also come at a cost when the effects of control are delayed.

Chapter 9. General Discussion

The series of experiments described in this thesis set out to examine the performance effects of different types of control used in two stages of the event counting cycle (refer to Figure 1.2 for model). It was hypothesized that control for the timing and appearance of events in what was referred to as the assimilate stage would facilitate the one-to-one binding of internal numbers to external items that is vital for accurate and efficient performance (Gallistel & Gelman, 1992; Carlson & Cassenti, 2004; Carlson & Stevenson, 2002). Two accounts were offered as explanations for the hypothesized effect – one citing a representational cause and the other a more perceptual cause. After finding initial evidence of an event control effect on counting performance in two preliminary experiments, the aim of Experiment 1 was to verify the effect using a second event counting paradigm. Experiments 2 and 3 were intended to assess the plausibility of the two proposed accounts of the event control effect. The main findings and their implications will be discussed in a following section of this chapter.

It was also hypothesized that the form of control used to determine when to end the counting process would also influence performance. In what was termed the compare stage of event counting, internal and external criteria were compared in terms of their relative effects on performance speed, accuracy, and metacognition for errors. A representational account proposed that an internal criterion should provide more precise information concerning the properties of the required goal state, and should provide a relative sense for how close one was to reaching it. External criteria, on the other hand, should only provide a more abstract conceptualization of the goal state and should garner no information about one's proximity to it. Due to these differences, the representation account asserts, counting should thus progress more quickly when using an internal criterion for determining when counting should end. A second account proposed that the two forms of criteria (internal and external) would differentially affect performance by means of their respective demands on cognition. Using an internal goal criterion was expected to incur an extra working memory cost for maintaining the additional goal state information and comparing that information against the current state at the end of each cycle. In contrast, using an external goal criterion would demand that more attentional resources be employed for monitoring the external environment in anticipation of the materialized goal state. Both the representational and cognitive demand accounts of the hypothesized goal criterion effect predicted a speed advantage for using an internal criterion, but neither made strong predictions about the benefits for accuracy and error monitoring since it wasn't clear whether speed should come at the cost of accuracy and error monitoring (Rabbitt, 2002) or instead serve as an indication of general performance benefit. Experiments 1 and 2 compared the counting performance of participants who used an internal criterion versus those who used an external criterion for controlling the cessation of counting, and also examined the possible interaction between compare stage criterion effects and the effects of event control in the assimilate stage.

9.1 Summary of Results

9.1.1 Experiment 1

Using a 2 (event type: brightening items, dimming items) x 2 (criterion: external signal, internal target number) between-subjects factorial design, Experiment 1 examined the effects of event control in the assimilate stage of counting, the effects of the goal criterion used in the compare stage of counting, and the effects of their interaction. Results were unable to sufficiently replicate the event control effects found in the preliminary experiments. Several findings did however suggest an effect of the goal criterion on counting performance. Participants who used an internal criterion – counting until a target number of items were reached – produced significantly larger-magnitude errors (yet made no greater number of errors overall) than those who used an external criterion and counted until an external signal occurred. Participants in the target criterion condition also performed reliably faster, were better able to discriminate their accurate from inaccurate performance, and produced significantly more undercounting errors than those who used the external form of the goal criterion.

9.1.2 Experiment 2

Experiment 2 used a 2 (event type: brightening items, dimming items) x 2 (criterion: external signal, internal target number) x 3 (event delay: 100 ms, 300 ms, 500 ms) mixed factorial design, to examine the impact of action-to-event temporal proximity on the event control effect. The event type and criterion manipulations were assigned between groups and the event delay was a within-groups factor. Based on the predictions of the representational account, it was initially thought that more temporal distance between one's actions and their resulting events would diminish the beneficial effects of event control. After finding little semblance of an event control effect in Experiment 1 however, it was questioned whether more temporal distance might instead *heighten* the benefits of using event information to mark the counting cycle. An increased need for placekeeping in the longer delay conditions was then expected to negate some of the placekeeping facilitation provided by the spatial nature of the array paradigm.

Findings revealed higher accuracy and a lower overall error magnitude in the internal criterion condition (i.e., when counting to a target number). There were more overcounting errors in the external goal criterion condition, and there was an even greater propensity for overcounting in this condition when the delay between actions and events was longer. The effects of event control were mostly found in the external goal criterion condition, in which item brightening led to faster performance and larger effects on error directionality. Overall, it was also revealed that increasingly long delays between actions and events led to an increasingly large performance speed difference between the two event type manipulations (brightening and dimming).

9.1.3 Experiment 3

In Experiment 3, a 2 (event type: brightening items, dimming items) x 2 (delay: 100 ms, 500 ms) completely between-subjects factorial design was used to assess the role of event delay consistency on the emergence of an event control effect on performance. A significant interaction between the event type and event delay manipulations only surfaced in the measure of performance rate. Results supported a perceptual salience account of the event control effect, which predicted a larger effect of the event type manipulation when the temporal distance between actions and events was longer, and that at these longer delays, dimming events would be more beneficial to counting rate.

9.1.4 Commonalities

Overall, there were some important commonalities among the experimental findings. Firstly, both the results of Experiment 1 and 2 revealed performance benefits associated with the use of an internal goal criterion condition (target condition) relative to an external goal criterion (signal condition). In Experiment 1, performing the target condition led to faster performance and better error monitoring; and in Experiment 2, performing the target condition led to faster performance, higher accuracy, and lower overall error magnitude. Taken together, the results reliably suggest that the type of goal criterion used in the compare stage of the counting cycle has an influential role on performance. In the more specific context of array counting, there seems to be a reliable advantage for using an internal goal criterion, either due to the benefits of enhanced representational specificity or to the nature of required cognitive demands.

Secondly, each of the experiments illustrated that control for the timing and appearance of items during counting can impact performance accuracy and efficiency, but in ways that depend on other parameters of the task. In the preliminary experiments, in which items were only distinguishable by temporal information and the goal criterion was always an external signal, performance tended to favor the more salient onset event control condition. However, in both the preliminary experiments and in Experiment 3, controlling the more salient onset and brightening events came at a cost when these events came after a temporal delay. Experiments 1 and 2 also suggested that the effects of event control are greater when a goal criterion emphasizes the need to attend to the external environment.

9.2 Limitations

One limitation of the current study is that the additional placekeeping information provided by the array paradigm made it difficult to directly compare the preliminary experiment results to the findings of the three thesis experiments. Distinguishing between items in the preliminary experiments' single-item display paradigm depended solely on temporal information, which may have encouraged strategic cycle marking in order to better coordinate the binding of internal numbers with external events. In the three main experiments however, distinguishing between items could be accomplished by using either, or both, the temporal or spatial information that was afforded by the array paradigm. This rather large difference between the two paradigms might explain the overall increase in accuracy going from the preliminary experimental paradigm to the main thesis experimental paradigm.

The relatively large experimental modifications between the three main experiments may have also contributed to making interpretation efforts more difficult. For example, the modifications between Experiment 2 and 3 involved both the change from a mixed block design to a pure block design as well as the elimination of an independent variable and a level of a second independent variable.

It was mentioned in a previous chapter that the brightening and dimming event types might not have been complete analogues to the preliminary experiment event types (onset and offset), and this factor might also have made it difficult to compare across the preliminary and main thesis experiments.

Finally, high accuracy rates in these experiments limited the amount of error and metacognitive data available for statistical analysis. Several participants counted with 100% accuracy and therefore contributed no data to metacognitive analyses or to the analysis of error magnitude and directionality for incorrect-trials.

9.3 Future Directions

The aforementioned limitations of the current experiments suggest at least two follow-up experiments to this thesis. One entails a return to the single-item display paradigm of the preliminary experiments, but requires that items be brightened and dimmed instead of turned on and off. This would resolve the problem of interpreting the contribution of spatial information for placekeeping and would address the degree of similarity between the on/off events and their intended analogs – brighten and dim. Another possible follow-up involves altering the temporal properties of the brighten and dim events in the array paradigm such that they become more analogous to the single-item display paradigm's on and off events. This could be accomplished by shortening the duration of the events so that they occur for the same amount of time as the on and off events had (250 ms) in the preliminary experiments, and would then return to their original state. The resulting events would be momentary item brightening/dimming and would appear more like a flicker than a permanent state change in the array. In essence, this should make the temporal properties of the two paradigms more similar and should help to clarify the impact of having both an immediate event and a delayed, opposite event follow one's actions instead of one immediate, lasting event.

9.4 Conclusion

The combined results of the experiments in this thesis suggest that the success and efficiency of routine skilled performance can be influenced both by the form of control used to facilitate internal-to-external information binding and the form of control used to compare current and goal states. Using an event counting task, a series of experiments demonstrated that when external actions are used to control the timing and appearance of external information required for one-to-one binding with internal information, this binding becomes less or more successful under different control conditions. The type of goal criterion used in assessing task completion also influenced performance and suggested that internal forms of a goal criterion may be more beneficial to routine performance than external forms that necessitate monitoring for environmental events.

APPENDIX A

OUTLIER DATA FROM EXCLUDED PARTICIPANTS

Experiment 1

Participant	Condition	Performance Measure	Mean Score	*Z*-score
79	Signal-Dim	Accuracy	17%	-4.924
		Abs. Error	1.90	6.674
		Signed Error	-1.50	-7.991
		Conf. (correct trials)	2.80	-2.955
88	Signal-Brighten	Conf. (correct trials)	2.35	-3.738
92	Signal-Brighten	Accuracy	43%	-3.078
		Abs. Error	0.89	2.755
95	Signal-Dim	Conf. (correct trials)	2.18	-4.031
96	Signal-Brighten	Conf. (correct trials)	2.82	-2.912
118	Target-Brighten	Signed Error	0.58	3.292
149	Target-Dim	Conf. (correct trials)	3.00	-2.607
167	Signal-Dim	Accuracy	28%	-4.137
		Abs. Error	1.36	4.575

Experiment 2

Participant	Condition	Performance Measure	Mean Score	*Z*-score
1	Target-Dim	Accuracy	38%	-3.521
		Abs. Error	1.00	3.214
		Signed Error	0.46	3.012
12	Signal-Brighten	Conf. (correct trials)	2.50	-4.026
20	Signal-Brighten	Accuracy	18%	-4.970
		Abs. Error	1.61	5.596
		Signed Error	-0.58	-3.831
22	Target-Brighten	Conf. (incorrect trials)	1.00	-2.658
44	Signal-Brighten	Signed Error	-0.59	-3.955
67	Signal-Dim	Conf. (incorrect trials)	1.00	-2.658
69	Target-Dim	Abs. Error	1.23	4.121
		Signed Error	-0.62	4.092
		Conf. (correct trials)	2.93	3.163
70	Target-Brighten	Conf. (incorrect trials)	1.00	-2.658
71	Signal-Dim	Accuracy	50%	-2.696
103	Signal-Dim	Rate (ms/step)	597	2.823
108	Signal-Brighten	Rate (ms/step)	586	2.696
115	Signal-Dim	Abs. Error	1.08	3.541
		Signed Error	0.42	2.722
		Conf. (correct trials)	2.71	-3.599
119	Signal-Dim	Signed Error	-0.58	-3.852

Experiment 3

Participant	Condition	Performance Measure	Mean Score	*Z*-score
77	Dim-100ms	Abs. Error	1.03	2.846
81	Dim-100ms	Accuracy	30%	-3.612
		Abs. Error	1.40	4.203
		Conf. (incorrect trials)	1.38	-3.306
		Conf. (correct trials)	1.44	-5.272
91	Brighten-100ms	Signed Error	-0.70	-3.659
120	Brighten-500ms	Signed Error	0.52	2.634
127	Brighten-100ms	Rate (ms/step)	475	2.647
144	Brighten-500ms	Conf. (correct trials)	2.00	-2.771

APPENDIX B

TABLES OF ALL STATISTICAL TESTS

Experiment 1

Table B1.

Experiment 1 – Analysis of Variance for Proportion Correct

Source	*df*	*MS*	*F*	η_p^2	*p*
Criterion (C)	1	.008	0.667	.005	.42
Event Type (E)	1	.019	1.643	.012	.20
C × E	1	.017	1.421	.010	.24
Error	135	(0.012)			

Note. Values enclosed in parentheses represent mean square errors.

Table B2.

Experiment 1 – Analysis of Variance for Overall Mean Signed Error

Source	*df*	*MS*	*F*	η_p^2	*p*
Criterion (C)	1	.009	0.701	.005	.40
Event Type (E)	1	.003	0.198	.001	.66
C × E	1	.004	0.313	.002	.58
Error	135	(0.013)			

Note. Values enclosed in parentheses represent mean square errors. Analysis includes all trials with error magnitudes between 0 and 5.

Table B3.

Experiment 1 – Chi Square Test Comparing Undercounts and Overcounts

Group	N negative errors	N positive errors	*df*	X^2	*p*
Signal-Brighten	70	36	1	11.09***	.00
Signal-Dim	91	83	1	0.39	.54
Target-Brighten	54	51	1	0.86	.77
Target-Dim	48	50	1	0.41	.84

Note. Chi square tests were conducted for each participant group in the experiment to assess the tendency for over- versus undercounting. An equal number of negative and positive errors would indicate no error direction bias.

*** $p < .01$.

Table B4.

Experiment 1 – Analysis of Variance for Undercount and Overcount Frequency

Source	*df*	*MS*	*F*	η_p^2	*p*
Undercount Frequency					
Criterion (C)	1	28.511	3.845**	.060	.05
Event Type (E)	1	.505	0.068	.001	.80
C × E	1	4.972	0.671	.011	.45
Error	60	(7.415)			
Overcount Frequency					
Criterion (C)	1	1.185	0.237	.004	.63
Event Type (E)	1	3.750	0.750	.012	.39
C × E	1	9.408	1.881	.030	.18
Error	60	(5.003)			

Note. Values enclosed in parentheses represent mean square errors.

** $p < .05$.

Table B5.

Experiment 1 – Analysis of Variance for Mean Absolute Error on Incorrect Trials

Source	*df*	*MS*	*F*	η_p^2	*p*
Criterion (C)	1	4.217	6.840***	.014	.01
Event Type (E)	1	.113	0.184	.000	.67
C × E	1	.350	0.568	.001	.45
Error	479	(0.617)			

Note. Values enclosed in parentheses represent mean square errors. Analysis includes all trials with error magnitudes between 1 and 5.

*** $p < .01$.

Table B6.

Experiment 1 – Analysis of Variance for Mean Cycle Time

Source	*df*	*MS*	*F*	η_p^2	*p*
Criterion (C)	1	45369.279	8.005***	.056	.01
Event Type (E)	1	1680.310	0.296	.002	.59
C × E	1	634.972	0.112	.001	.74
Error	135	(5667.483)			

Note. Values enclosed in parentheses represent mean square errors.

*** $p < .01$.

Table B7.

Experiment 1 – Analysis of Variance for Mean Cycle Time by Task Block

Source	*df*	*MS*	*F*	η_p^2	*p*
Block (B)	3	138322.673	58.843***	.304	.00
B × C	3	721.953	0.307	.002	.82
B × E	3	681.301	0.290	.002	.83
B × C × E	3	2241.341	0.953	.007	.42
Error	405	(2350.705)			

Note. Values enclosed in parentheses represent mean square errors.

*** $p < .01$.

Table B8.

Experiment 1 – Within-subjects Contrasts for Mean Cycle Time by Task Block

Source	*df*	*MS*	*F*	η_p^2	*p*
Block					
- Linear	1	404022.510	86.516***	.391	.00
- Quadratic	1	9950.530	6.927***	.049	.01
- Cubic	1	994.980	1.052	.008	.31

Note. *** $p < .01$.

Table B9.

Experiment 1 – Parameter Estimates of the Criterion Main Effect on Cycle Time

Source	*SE*	*t*	η_p^2	*p*
Block 1	23.298	0.951	.157	.34
Block 2	22.138	2.084**	.544	.04
Block 3	19.630	2.329**	.638	.02
Block 4	17.189	2.203**	.035	.03

Note. ** $p < .05$.

Table B10.

Experiment 1 – Analysis of Variance for Rate Coefficient of Variation

Source	*df*	*MS*	*F*	η_p^2	*p*
	Between subjects				
Criterion (C)	1	0.001	0.039	.000	.84
Event Type (E)	1	0.001	1.087	.008	.30
C × E	1	0.012	0.546	.004	.46
Error	134	(0.021)			
	Within subjects				
Block (B)	3	0.005	0.374	.003	.78
B × C	3	0.004	0.323	.002	.81
B × E	3	0.009	0.699	.005	.55
B × C × E	3	0.033	2.242	.016	.08
Error (B)	402	(0.012)			

Note. Values enclosed in parentheses represent mean square errors.

Table B11.

Experiment 1 – Analysis of Variance for Mean Confidence Ratings

Source	*df*	*MS*	*F*	η_p^2	*p*
	Between subjects				
Criterion (C)	1	7.247	8.713***	.075	.00
Event Type (E)	1	0.073	0.087	.001	.77
C × E	1	0.025	0.030	.000	.86
Error	108	(0.832)			
	Within subjects				
Accuracy (A)	1	33.986	89.781***	.454	.00
A × C	1	5.250	13.869***	.114	.00
A × E	1	0.009	0.025	.000	.88
A × C × E	1	0.079	0.208	.002	.65
Error (A)	108	(0.379)			

Note. Values enclosed in parentheses represent mean square errors.

*** $p < .01$.

Table B12.

Experiment 1 – Parameter Estimates of the Criterion Main Effect on Confidence

Source	*SE*	*t*	η_p^2	*p*
Incorrect Trials	0.264	2.588***	.058	.01
Correct Trials	0.123	-.041	.000	.97

Note. *** $p < .01$.

Experiment 2

Table B13.

Experiment 2 – Analysis of Variance for Proportion Correct

Source	*df*	*MS*	*F*	η_p^2	*p*
	Between subjects				
Criterion (C)	1	0.504	19.275***	.149	.00
Event Type (E)	1	0.002	0.064	.001	.80
C × E	1	0.022	0.836	.008	.36
Error	110	(0.026)			
	Within subjects				
Delay (D)	2	0.014	1.806	.016	.17
D × C	2	0.007	0.919	.008	.40
D × E	2	0.013	1.744	.016	.18
D × C × E	2	0.000	0.053	.000	.95
Error (D)	220	(0.008)			

Note. Values enclosed in parentheses represent mean square errors.

*** $p < .01$.

Table B14.

Experiment 2 – Analysis of Variance for Overall Mean Signed Error

Source	*df*	*MS*	*F*	η_p^2	*p*
	Between subjects				
Criterion (C)	1	0.043	1.532	.014	.22
Event Type (E)	1	0.116	0.571	.005	.45
C × E	1	0.004	0.134	.001	.72
Error	110	(0.028)			
	Within subjects				
Delay (D)	2	0.009	0.429	.004	.65
D × C	2	0.016	0.766	.007	.47
D × E	2	0.019	0.892	.008	.41
D × C × E	2	0.074	3.451**	.030	.03
Error (D)	220	(0.021)			

Note. Values enclosed in parentheses represent mean square errors. Analysis includes all trials with error magnitudes between 0 and 5.

** $p < .05$.

Table B15.

Experiment 2 – Within Subjects Contrasts for Overall Mean Signed Error

Source	*df*	*MS*	*F*	η_p^2	*p*
Delay (D)					
linear	1	0.017	0.939	.008	.34
quadratic	1	0.001	0.036	.000	.85
D × C					
linear	1	0.033	1.745	.016	.19
quadratic	1	0.000	0.010	.000	.92
D × E					
linear	1	0.001	0.071	.001	.79
quadratic	1	0.037	1.526	.014	.22
D × C × E					
linear	1	0.079	4.257**	.037	.04
quadratic	1	0.068	2.828	.025	.10
Error (D)					
linear	110	(0.019)			
quadratic	110	(0.024)			

Note. Values enclosed in parentheses represent mean square errors. Analysis includes all trials with error magnitudes between 0 and 5.

** $p < .05$.

Table B16.

Experiment 2 – Analysis of Variance for Overall Mean Absolute Error

Source	*df*	*MS*	*F*	η_p^2	*p*
	Between subjects				
Criterion (C)	1	0.807	14.673***	.118	.00
Event Type (E)	1	0.013	0.232	.002	.63
C × E	1	0.135	2.450	.022	.12
Error	110	(0.055)			
	Within subjects				
Delay (D)	2	0.025	1.289	.012	.28
D × C	2	0.035	1.836	.016	.16
D × E	2	0.017	0.908	.008	.41
D × C × E	2	0.002	0.087	.001	.92
Error (D)	220	(0.019)			

Note. Values enclosed in parentheses represent mean square errors. Analysis includes all trials with error magnitudes between 0 and 5.

*** $p < .01$.

Table B17.

Experiment 2 – Analysis of Variance for Mean Item Request Time

Source	*df*	*MS*	*F*	η_p^2	*p*
		Between subjects			
Criterion (C)	1	93050.449	5.416**	.047	.02
Event Type (E)	1	150240.136	8.745***	.074	.00
C × E	1	85492.454	4.976**	.043	.03
Error	110	(17181.099)			
		Within subjects			
Delay (D)	1.7	2764.178	2.654*	.024	.08
D × C	1.7	1486.942	1.428	.013	.24
D × E	1.7	4273.454	4.103**	.036	.02
D × C × E	1.7	2425.695	2.329	.021	.11
Error (D)	191.1	(904.620)			

Note. Values enclosed in parentheses represent mean square errors, and within subjects effects display a Greenhouse-Geisser adjustment for sphericity.

***$p < .01$, **$p < .05$, *$p < .10$.

Table B18.

Experiment 2 – Within Subjects Contrasts for Mean Item Request Time

Source	*df*	*MS*	*F*	η_p^2	*p*
Delay (D)					
linear	1	474.830	0.372	.003	.54
quadratic	1	4326.377	7.790***	.066	.01
D × C					
linear	1	1426.310	1.138	.010	.29
quadratic	1	1156.417	2.082	.019	.15
D × E					
linear	1	6388.792	5.095**	.044	.03
quadratic	1	1033.934	1.862	.017	.18
D × C × E					
linear	1	3571.174	2.848*	.025	.09
quadratic	1	642.109	1.156	.010	.29
Error (D)					
linear	110	(1253.877)			
quadratic	110	(555.362)			

Note. Values enclosed in parentheses represent mean square errors.

*** $p < .01$, ** $p < .05$, * $p < .10$.

Table B19.

Experiment 2 – Analysis of Variance for Mean Confidence Ratings

Source	*df*	*MS*	*F*	η_p^2	*p*
	Between subjects				
Criterion (C)	1	1.085	0.730	.021	.40
Event Type (E)	1	1.752	1.178	.033	.29
C × E	1	4.996	3.359*	.090	.08
Error	34	(1.487)			
	Within subjects				
Accuracy (A)	1	12.353	35.967***	.514	.00
A × C	1	0.004	0.012	.000	.91
A × E	1	0.555	1.616	.045	.21
A × C × E	1	0.746	2.172	.060	.15
Error (A)	34	(0.343)			
Delay (D)	2	0.245	0.966	.028	.39
D × C	2	0.314	1.238	.035	.30
D × E	2	0.007	0.028	.001	.97
D × C × E	2	0.096	0.377	.011	.69
Error (D)	68	(0.254)			
A × D	2	0.331	1.050	.030	.36
A × D × C	2	0.314	0.995	.028	.38
A × D × E	2	0.083	0.263	.008	.77
A × D × C × E	2	0.380	1.204	.034	.31
Error (A × D)	68	(0.316)			

Note. Values enclosed in parentheses represent mean square errors.

***$p < .01$, *$p < .10$.

Experiment 3

Table B20.

Experiment 3 – Analysis of Variance for Proportion Correct

Source	*df*	*MS*	*F*	η_p^2	*p*
Event Type (E)	1	.003	0.216	.004	.64
Delay (D)	1	.034	2.313	.038	.13
E × D	1	.000	0.000	.000	.98
Error	59	(0.015)			

Note. Values enclosed in parentheses represent mean square errors.

Table B21.

Experiment 3 – Analysis of Variance for Overall Mean Signed Error

Source	*df*	*MS*	*F*	η_p^2	*p*
Event Type (E)	1	.083	4.318**	.068	.04
Delay (D)	1	.125	6.516**	.099	.01
E × D	1	.005	0.016	.000	.90
Error	59	(0.036)			

Note. Values enclosed in parentheses represent mean square errors. Analysis includes all trials with error magnitudes between 0 and 5.

** $p < .05$.

Table B22.

Experiment 3 – Analysis of Variance for Overall Mean Absolute Error

Source	*df*	*MS*	*F*	η_p^2	*p*
Event Type (E)	1	.006	0.166	.003	.69
Delay (D)	1	.125	3.530*	.056	.06
E × D	1	.005	0.016	.002	.71
Error	59	(0.036)			

Note. Values enclosed in parentheses represent mean square errors. Analysis includes all trials with error magnitudes between 0 and 5.

* $p < .10$.

Table B23.

Experiment 3 – Analysis of Variance for Mean Item Request Time

Source	*df*	*MS*	*F*	η_p^2	*p*
Event Type (E)	1	24466.140	6.641**	.101	.01
Delay (D)	1	14840.459	4.028**	.064	.05
E × D	1	14577.134	3.956**	.063	.05
Error	59	(3684.375)			

Note. Values enclosed in parentheses represent mean square errors.

** $p < .05$.

Table B24.

Experiment 3 – Analysis of Variance for Mean Confidence Ratings

Source	*df*	*MS*	*F*	η_p^2	*p*
	Between subjects				
Event Type (E)	1	1.516	2.813	.050	.10
Delay (D)	1	2.215	4.110**	.072	.05
E × D	1	0.016	0.030	.001	.86
Error	53	(0.539)			
	Within subjects				
Accuracy (A)	1	6.521	58.872***	.526	.00
A × E	1	0.287	2.595	.047	.11
A × D	1	0.183	1.648	.030	.21
A × E × D	1	0.009	0.084	.002	.77
Error (A)	53	(0.111)			

Note. Values enclosed in parentheses represent mean square errors.

***$p < .01$, **$p < .05$.

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