Investigating Performance Under Two Forms of Temporal Cueing

by

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Submitted in partial fulfilment of the requirements

for the degree of Master of Science

at

Dalhousie University

Halifax, Nova Scotia

July, 2020

DEDICATION PAGE

This thesis is dedicated to my loving parents and brother. Without your constant support and encouragement, this would not have been possible.

TABLE OF CONTENTS

List of Tables

List of Figures

Abstract

Temporal attention is the focusing of cognitive resources to an interval in time to prepare a response and improve perception. Recently, it has been shown that there are two independent forms of temporal attention: one elicited by purely endogenous alerting mechanisms, and one elicited through a combination of both endogenous and exogenous alerting mechanisms (McCormick et al., 2018). While these both improve performance at validly cued intervals, more informative speed and accuracy comparisons were not possible due to them being measured during a detection task. The current pair of experiments looks to compare these two forms of temporal attention in a discrimination task, while measuring both speed and accuracy, by making methodological modifications that lower task demand. This marks the first study to observe benefits to temporal cueing in a discrimination task for both the combined and purely endogenous temporal attention conditions. Speed and accuracy relationships are further discussed.

List of Abbreviations and Symbols Used

SOA	Stimulus Onset Asynchrony
RT	Reaction Time
ER	Error Rate
AIC	Akaike’s information criterion
Δ	Delta

Acknowledgements

I would like to thank my supervisor Raymond Klein for everything he has done for me over the last four and half years. I am very grateful to have you as a mentor and for all the opportunities you have provided to garner my success. Additionally, I am thankful for your intellectual and editorial guidance on this thesis. I would also like to extend thanks to Ralph Redden. I am so fortunate that Ralph invited me into the Klein lab, and even more fortunate that he is a patient mentor and important friend. I look forward to many more collaborations in the future. Additionally, I would like to thank the members of the Klein lab for creating a supportive, loving, and fun environment that made research a joy (which is not always an easy feat), specifically Swasti, Brett, Austin, Nik, Jon, Richard, and everyone else I missed.

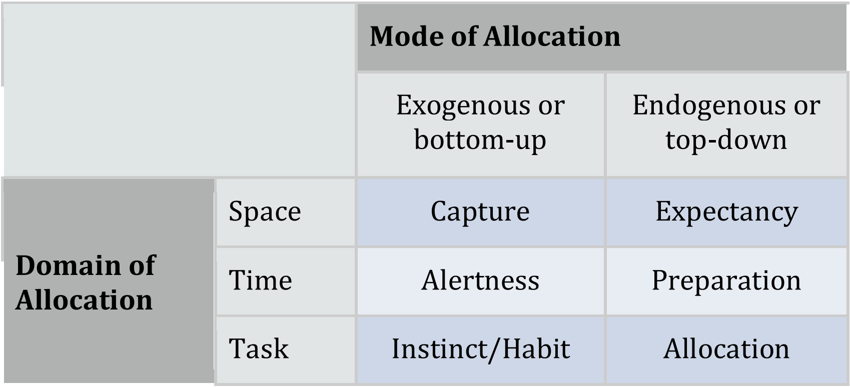
I am also thankful for my other supervisor, Jason Ivanoff, who welcomed me into his lab and provided his own perspectives on how to conduct cognitive science. Also, thanks to Aaron Newman and David Westwood for agreeing to take part in this process as committee members.

Finally, there are all of my family and friends who contributed to this project in spirit by allowing me rant about topics they certainly did not care about or understand, sharing drinks after long days, and being supportive and encouraging of what I am pursuing. I am fortunate that there are too many of them to name, but if you are reading this, you are certainly one

CHAPTER 1 INTRODUCTION

1.1 What is Attention

Attention is a set of cognitive mechanisms that aids in the perception of our internal and external environments. Posner and Petersen popularized the three-component model for attention made up of alerting, orienting, and executive functioning (1990). These three components are anatomically distinct and contribute different attentional functions. Alerting generates and maintains arousal. Orienting focuses attentional resources to increase perception. Executive functioning filters information to ensure an individual can focus attention on relevant information (Posner and Petersen, 1990). The Attention Network Test (ANT) is a short task that allows for the evaluation of these aforementioned networks, and potentially displays uncorrelated functioning (Fan et al., 2002). Expanding upon this three-part taxonomy, Klein and Lawrence (2012) have proposed adding 'domain of allocation' and 'mode of allocation' across these previously outlined mechanisms (see figure 1). *Domain* refers to whether attention is allocated in space, time, or task. *Mode* refers to whether attention is elicited exogenously or endogenously. Exogenous elicitation is bottom-up and a reflexive response to salient stimuli. Endogenous elicitation is top-down and typically established through learned contingencies between paired stimuli (Klein and Lawrence, 2012). By adding these distinctions, researchers can better study and delineate how attentional mechanisms impact performance under a variety of conditions.



		Mode of Allocation	
		Exogenous or bottom-up	Endogenous or top-down
Domain of Allocation	Space	Capture	Expectancy
	Time	Alertness	Preparation
	Task	Instinct/Habit	Allocation

Figure 1: Klein and Lawrence’s extended taxonomy for attention, including mode and domain of allocation.

1.2 Alerting

As mentioned, alerting refers to the generation and maintenance of arousal. There are, however, two different types: *tonic* and *phasic*. The main differentiating feature between these two types is the time-course in which it affects an individual. Tonic alerting occurs across a longer time span. For instance, tonic changes in arousal throughout the day are typically aligned with circadian rhythms (Posner, 1975). Phasic alerting, in contrast, typically increases arousal on a scale of seconds in response to some event. When a phasic alerting response is elicited, it is associated with increased activity in the locus coeruleus, an area that produces norepinephrine (Aston-Jones and Cohen, 2005). This has been shown to result in decreased response speed without affecting the rate of information processing (Posner, Klein, Summers, and Buggie, 1973; McCormick, Redden, Hurst, and Klein, 2019). Because the rate of information processing, which is what allows participants to make judgements about task-related events, is constant during an alerting response, participants may be responding with a lower quality of information present. The relation between response speed and processing speed is important to consider in relation to alerting, as increased arousal does not necessarily indicate improved performance as it may generate this trade-off between the speed and error rate (Wicklegren, 1977).

Although this thesis will be mainly focused on the impact of different forms of phasic alerting, one must still understand that the effects of tonic alerting are present and may contribute to performance during an experiment. As alertness can be elicited based on long-term contingencies, there can be differences across experimental conditions that are best explained by tonic alerting (Kingstone, 1992). For instance, McCormick et al. performed an experiment comparing intense and isointense (or delta 0 dB; see Figure 2) auditory warning signals in a between-participant design (2019). In both signal-intensity manipulations, there were trials for which signals were not presented and phasic alerting was not manipulated. Although these types of trials are identical across intensity conditions, the 'no signal' trials had a faster mean reaction time in the intense condition in comparison to the isointense condition. This indicates that there may have been a shift in tonic arousal based on the participant's continual experience with signal intensity.

Phasic alerting has a long history of study dating back to some of the earliest years of psychology (Wundt, 1904). This is perhaps due to its simplistic methodological design: a warning stimulus (WS) of some sort is presented, which indicates that the participant should prepare for the presentation of a target. The target is then presented, and participants must respond as quickly as possible. The technique of mental chronometry is popular for studying the cognitive processes involved in tasks such as this. Performance, as defined by reaction time, represents the sum time it takes for a series of mental operations to execute a measured action. Each of these operations requires some amount of measurable time. By comparing different methodological conditions that attempt to target particular mental operations, we can get a better understanding of what makes up these mental operations (Sternberg, 1969; Niemi & Naataen, 1981). In relation to phasic alerting in a simple WS-target paradigm, participants are significantly faster when presented with a warning signal in comparison to when there is no warning signal (for an older review of the literature, see Klemmer, 1956). In research using EEG, warning signals are shown to typically generate an event-related potential (ERP) referred to as *'contingent negative variation'*, or CNV (Walter et al., 1964). CNV is recognized as having two separate waves: an earlier increase in activity occurs after the presentation of the warning signal that is thought to be related to task orienting. This is called the *O-wave*. The later wave of this potential is associated with motor preparation for the target, or expectancy, and is called the *E-wave* (Rohrbaugh & Gaillard, 1983).

Participants are faster when a consistent interval is used between the signal and target, in comparison to a variable interval. This is evidence participants are able to focus their response-readiness to a learned interval during the duration of an experiment (Naatanen, Muranen, and Merisalo, 1975). However, participants are also capable of reorienting their attention in time rather quickly and can logically deduce the increasing probability that a target will appear in the response period. For example, if the possible intervals include 500 ms, 1000 ms, and 2000 ms, once the 500 ms interval elapses, the participant knows that the target will appear at one of the two remaining times. Once the 1000 ms interval passes, they can be confident it will appear at 2000 ms, and performance displays that this deduction improves response performance. This is referred to as hazard sensitivity (for a review, see Nobre and van Ede, 2018). If this is of concern to the experimenter, they can use catch trials to partially offset this effect. Catch trials are trials in which the target stimulus is not presented. When these are included, a participant cannot be confident that a target would be presented at the longest possible interval (see Correa et al., 2004; Lawrence and Klein, 2013). One situation in which interval uncertainty is less likely to influence performance is when signal intensity is high, likely due to it reflexively alerting participants.

This offsets some of the negative effect that having variable interval length has on a participant's ability to volitionally prepare for a target (Bernstein, Chu, Briggs, and Schurman, 1973). This typical contingency in alerting research, with the warning signal indicating that a target will be presented in close temporal proximity, will be elaborated upon as one of the forms of temporal attention.

There is a significant body of work outlining the distinctions between endogenous and exogenous orienting in the spatial domain (Klein, 2009). Notably, this research indicates that these two modes of spatial attention recruit different neural mechanisms and affect performance differently during experimental paradigms, providing evidence for the importance of including this distinction in the taxonomy of attention (Klein and Lawrence, 2012). Until recently, research in the domain of alerting, a form of orienting in the temporal domain, largely lacks this distinction due to confounding endogenous and exogenous control (Lawrence and Klein, 2013). When attempting to study the effect of exogenous alerting on task performance, researchers manipulate signal intensity and observe a positive relationship with response speed (as intensity increases, response speed decreases) (Loveless and Sanford, 1975; Niemi 1982). Manipulations of signal intensity include changing decibel level, how long the signal plays, and the interval between the signal and the target being presented. However, researchers in these experiments have confounded endogenous alerting. Participants quickly learn that the presentation of a signal means a target will soon be presented. This learned association allows for participants to *volitionally* prepare for the presentation of a target based on a signal. One method that has been used to try to limit the influence of endogenous components is implementing a *'non-aging foreperiod'* (Nickerson and Burnham, 1969). A non-aging foreperiod is an exponential distribution of stimulus onset asynchronies (SOAs) across trials so that participants do not know how long of an interval there will be between a warning signal and target. However, the consistency in which stimuli are presented in a particular order, where signals always predict that a target is next in sequence, allows for the recruitment of endogenous mechanisms even in this method which minimizes the possibility of precise anticipation of stimuli (Lawrence and Klein, 2013). Similarly, studies that attempt to isolate endogenous temporal attention typically use a signal that reflexively alerts participants in some way by increasing in intensity, whether that be through an increase in volume (auditory warning signal), brightness (visual warning signal), or stimulation (tactile warning signal). This elicits exogenous mechanisms, which confounds their ability to analyze purely endogenous mechanisms.

For these reasons, Lawrence and Klein (2013) developed a novel methodology to better isolate these two forms of temporal attention and observe how they may differently impact human performance. They utilized Rescorla's (1967) 'truly random procedure' to minimize the possibility of eliciting endogenous mechanisms. This procedure, which was developed for research on animal learning, involves presenting signals and targets independently of one another. In a non-contingent design, signals (S) and targets (T) can occur in any pattern (ex: T-T-S-T-S-S-S). This makes it so there are no learned contingencies between these stimuli. In contrast, a contingent design presents signals and targets in a predictable pattern, so that the presentation of a signal indicates the next event will be a target (ex: S-T-S-T-S-T). For non-contingent designs, analysis involves retrospectively going through the data to identify instances where the signal was presented before the target for analysis. This reduces the influence of top-down processes and allows researchers to independently observe the effect of exogenous alerting.

To mitigate the influence of exogenous mechanisms during the study of endogenous mechanisms, Lawrence and Klein developed a dichotic signalling technique. Participants are presented with diotic, or mono (correlated to each ear), white noise through a pair of headphones throughout the experiment. This means the same static frequency is played in each ear. The presentation of the signal involves a temporary (100ms) shift from *diotic* to *dichotic* (stereo; uncorrelated sound to each ear) sound. This allows for a subjectively salient event which does not require an increase in intensity, analogous to an isoluminant colour-change (Lawrence and Klein, 2013). In doing so, participants have the ability to volitionally prepare for upcoming stimulus events, while minimizing the influence of exogenous alerting.

By manipulating contingency and intensity conditions, Lawrence and Klein were able to compare how these two mechanisms differently impacted performance (see Figure 2).

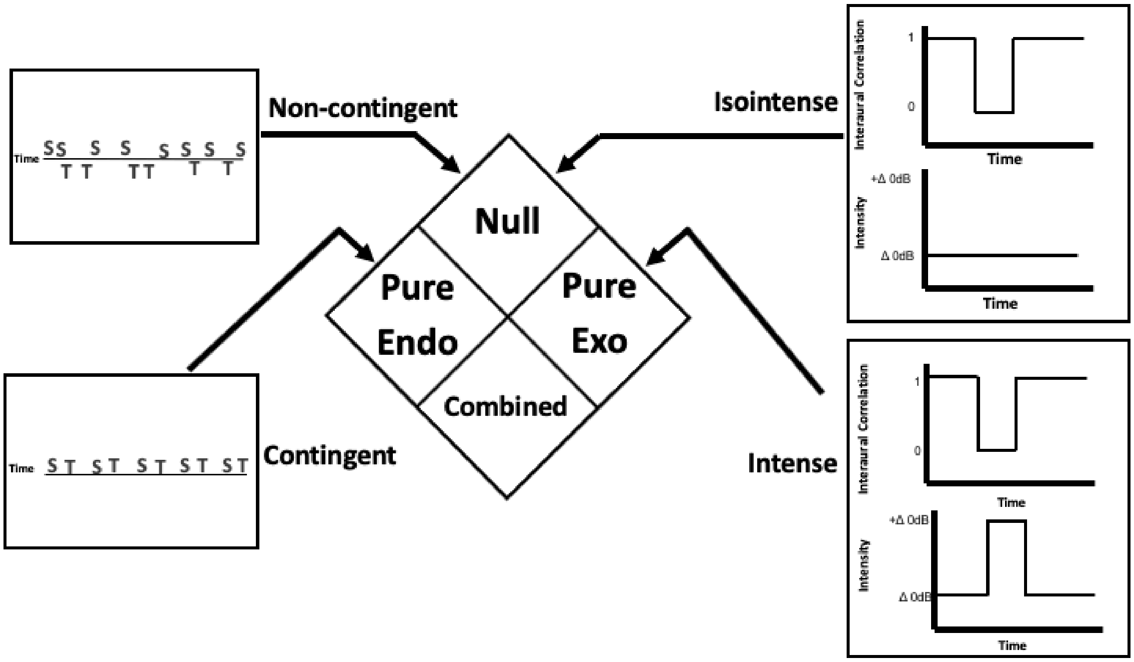


Figure 2: A breakdown of the different possible combinations in Lawrence and Klein's experimental design. The two contingency manipulations (contingent, noncontingent) are outlined on the left, and the two signal intensity manipulations (isointense, intense) are outlined on the right. Image redrawn from Lawrence and Klein, 2013.

A ‘purely endogenous’ condition involves a contingent design with isointense signals. This is because participants can prepare using the predictive nature of the signal without eliciting reflexive alerting. A ‘purely exogenous’ condition involves a non-contingent design with intense signals, as differences in performance will mainly come from reflexively generated alerting. A ‘combined’ condition involves a contingent design with intense signals, eliciting mechanisms related to both exogenous and endogenous temporal attention. It is worth noting that the ‘combined’ condition is representative of most research done in temporal attention, as temporal cue stimuli are predictably presented before targets using some salient alteration of sound or vision (Weinbach and Henik, 2012). A ‘null’ condition involves a non-contingent design with an isointense signal. This null condition produces the poorest reaction time and accuracy performance of these intensity and contingency combinations, as the stimuli are non-predictive and do not increase in intensity, so it does not reliably recruit endogenous or exogenous temporal mechanisms. The two pure alerting conditions are compared to this null condition, as they either add intensity (purely exogenous) or contingency (purely endogenous) to their methodology. Purely exogenous alerting improved reaction times without any cost to accuracy (Figure 3, Pure Exo). Purely endogenous alerting improved both reaction time and accuracy (Figure 3, Pure Endo). In the combined condition (Figure 3, Combined), which elicits both forms of temporal attention, a speed-accuracy trade-off was observed in comparison to the purely endogenous condition. These two are compared because the only difference in design is the addition of intensity in the combined condition. This means a decrease in reaction time was met with an increase in error rate. Purely endogenous and exogenous conditions produced pure improvements to performance, while the combined condition instead shows a change in performance criterion.

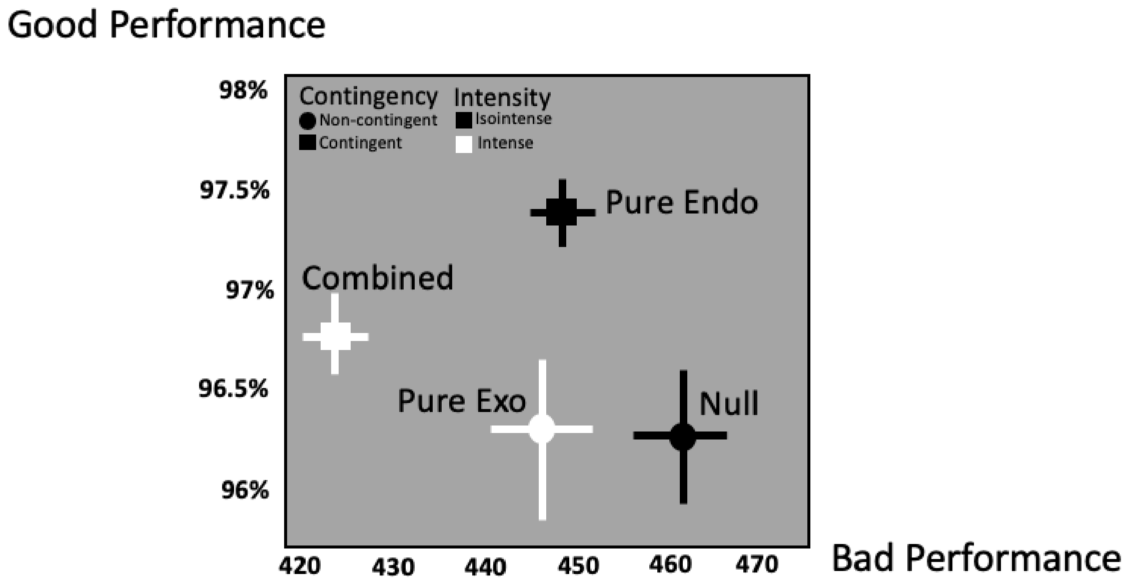


Figure 3. The redrawn results from Lawrence and Klein (2013) mapped in speed-accuracy space. A = the purely exogenous condition, B = purely endogenous condition, C = the combined condition, D= the null condition. Performance is best in the top left-hand corner (fast and accurate) and worst in the bottom right-hand corner (slower and less accurate). The error bars are 95% confidence intervals for both RT (horizontal) and accuracy (vertical).

As reported by the authors, this was the first evidence of 'separable, but interactive modes of exogenous and endogenous temporal attention' (page 567, 2013), an important step for furthering the research of dissociable mechanisms in temporal attention.

1.3 Temporal Cueing and the Kingstone Paradigm

Temporal cueing (or 'temporal orienting') is the focusing of attentional resources to a particular interval based on information provided by a cue. Kingstone introduced a paradigm to study this cognitive mechanism in 1992. In a five-part experiment, he studied how visual cues for various target qualities and modalities may interact with one another. In experiment four, participants received a cue to indicate the likely target form (cues were 1 and 2 to predict 'A' or 'V' letter stimuli, respectively) and a temporal cue which indicated when a target was likely to occur (cues were ‘S’ and ‘L’ to predict a short [400ms] or long [1600ms] interval). Both of these cues were 80% predictive. The temporal cue is analogous to the seminal spatial cueing paradigm developed by Posner (1980). Participants were faster when presented with valid temporal cues compared to invalid temporal cues, which was later defined as a temporal cueing effect (Correa et al., 2004). Later, in 1998, Coull and Nobre inappropriately garnered credit for developing this paradigm, only giving Kingstone a passing acknowledgement. Unfortunately, as noted by McCormick et al. (2018), the field of temporal attention accepted this inaccuracy. In spite of it being known as Coull and Nobre’s paradigm, we will be referring to it as the Kingstone paradigm. In Coull and Nobre’s study, they compared neural correlates of spatial and temporal cueing using a slightly modified two-cue Kingstone paradigm. One cue identified the likely spatial location, and the other identified the likely temporal interval. One set of participants completed the study with PET recording, and another with fMRI recording. Behaviorally, as previously reported by Kingstone (1992), the two forms of cues displayed similar valid-cue advantages in response time. There was a significant amount of overlap between the different brain areas involved in spatial and temporal cueing, however, temporal attention seems to activate the left intraparietal sulcus and left inferior premotor cortex, while spatial attention activates the right intraparietal sulcus, displaying distinctions between these two mechanisms.

Since these early temporal cueing studies, temporal attention has become a burgeoning field (Nobre & van Ede, 2018). In this time, four distinct types of temporal attention have been recognized and categorized (see Nobre and van Ede, 2018 for a complete review). The first type is called *temporal associations* and involves the use of cues that indicate the likely upcoming interval. This is what was previously described above with the Kingstone paradigm (Kingstone, 1992; Coull and Nobre, 1998). The second is *hazard rates*, or what was previously referred to as hazard sensitivity (see page 4). This relates to learned probability-associations for when a target is likely to appear. Reaction times are fastest when targets appear at more-probable SOAs compared to less probable SOAs, as participants selectively allocate attention based on learned temporal associations during a task (Cravo, Rohenjohl, Wyart, and Nobre, 2011). The third categorization is *rhythmic temporal attention*, which has been categorized as a reflexive, or exogenous, form of temporal attention (Rohenhohl, Coull, and Nobre, 2011). In these experiments, temporal information is typically provided via some rhythmic, isochronous stimulus. Then, the target is either presented at the rhythmic interval, or outside the rhythmic interval. Participants are faster when the target is presented at the rhythmic interval, as opposed to offbeat, regardless of rhythmic cue validity (Rohenkohl, Coull, and Nobre, 2011; Sanabria, Capizzi, and Correa, 2011). This kind of temporal attention is analogous to exogenous spatial orienting as in both types the pre-target event (cue or rhythmic sequence) is uninformative about the target location (in space and time, respectively; Posner, 1980). The fourth categorization is *temporal sequences,* which involves executing particular action within a temporal array of cues. This is similar to rhythmic temporal attention, but involves learning more complex sequences, like one would execute while playing music (Nobre and van Ede, 2018). Participants are faster to perform an action when a sequence is repeated than when it is random, as participants can use elements of a sequence to temporally prepare to make a specific response (Reed and Johnson, 1994). When multiple forms of temporal cueing are elicited during a task, it appears they can produce either additive or interactive effects (Nobre and van Ede, 2018), emphasizing a need to control for whatever particular form is of interest to a studies' research objectives.

The study of temporal attention is important to expand our understanding of the taxonomy of attention, and cognition as a whole, but there are also a number of applied areas which involve this mechanism and can directly benefit from the knowledge produced. For instance, when playing tennis, an athlete must have an accurate perception of when the ball engages with the other players racquet in order to effectively predict where it is likely going to end up (Denison, Yuval-Greenberg, and Carrasco, 2019). This is true of any sport in which objects move at such high velocities that they can become untrackable with the human eye (other examples include baseball or hockey). It is also an important process for interpreting language and music (Astheimer and Sanders, 2009; Tillmann, 2012), where attention has been shown to focus on anticipated intervals to improve perception. Additionally, there is evidence that presenting information in predictable sequences leads to improvements in memory performance (Thavabalasingam, O'Neil, Zeng, and Lee, 2016) and has been cited in the learned associations of classical conditioning, as the temporal expectancy of receiving a stimulus is strongly associated with how well two stimuli are paired together (Solomon, Vander Schaaf, Thompson, and Weisz, 1986; Nobre and van Ede, 2018).

Although all presented categorizations of temporal attention have the potential for further exploration, our references to temporal cueing and temporal attention will be related to temporal associations, involving the use of symbolic temporal cues. Temporal cueing improves reaction time performance in both discrimination and detection tasks (Correa et al., 2004). While the study of reaction time has been important for understanding temporal cueing, studies typically neglect discussing error rate. This is potentially due to the typical 'non-significant' finding when running ANOVAs[1], or due to the precedent that has been set due to past published research in the field (see table 1).

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[1] ANOVAs are a common form of analysis in the field of temporal cueing, although it is not appropriate for the binomial distribution that correct/incorrect error rate generates.

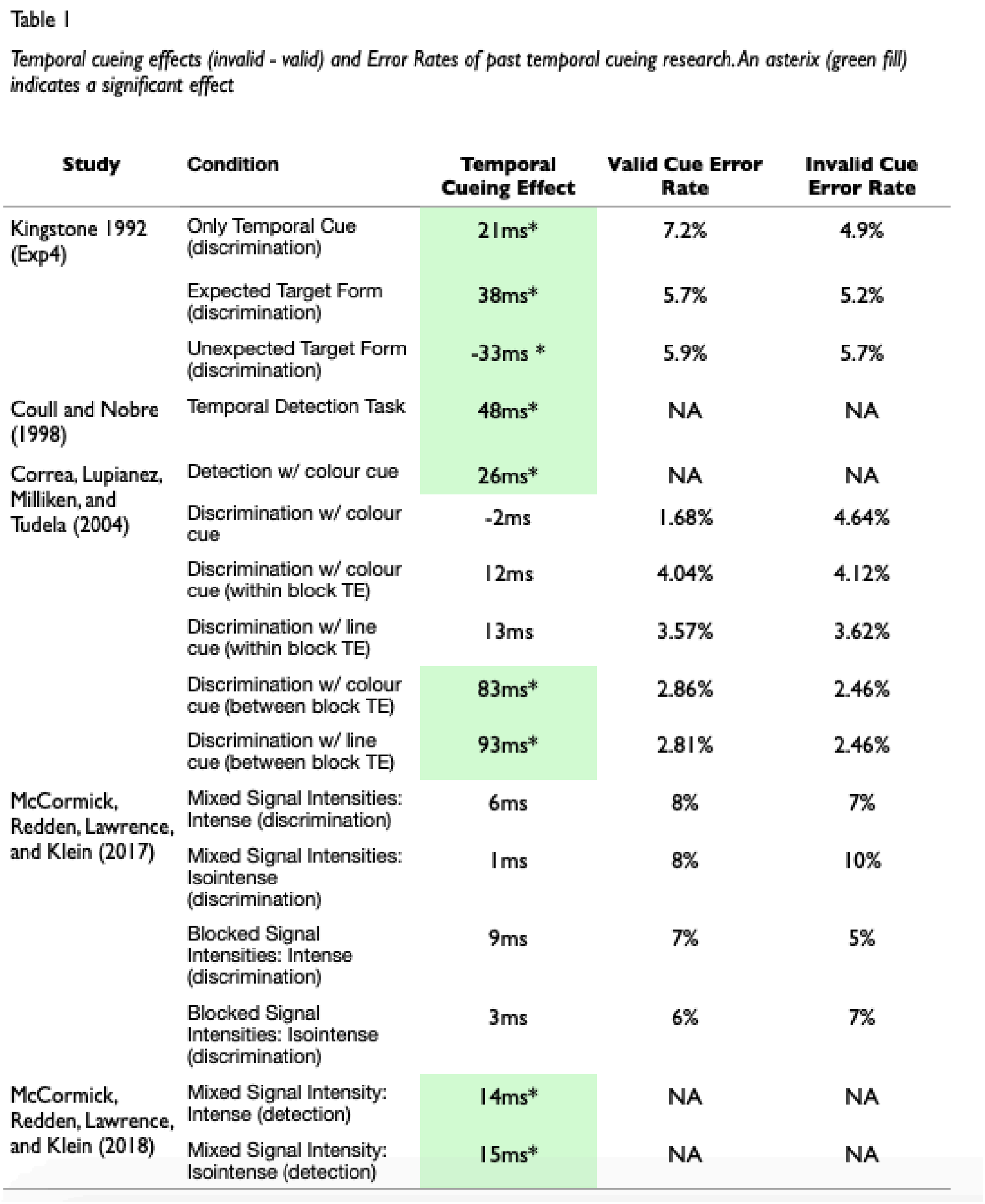

Table 1

Temporal cueing effects (invalid - valid) and Error Rates of past temporal cueing research. An asterix (green fill) indicates a significant effect

Study	Condition	Temporal Cueing Effect	Valid Cue Error Rate	Invalid Cue Error Rate
Kingstone 1992 (Exp4)	Only Temporal Cue (discrimination)	21ms*	7.2%	4.9%
	Expected Target Form (discrimination)	38ms*	5.7%	5.2%
	Unexpected Target Form (discrimination)	-33ms *	5.9%	5.7%
Coull and Nobre (1998)	Temporal Detection Task	48ms*	NA	NA
Correa, Lupianez, Milliken, and Tudela (2004)	Detection w/ colour cue	26ms*	NA	NA
	Discrimination w/ colour cue	-2ms	1.68%	4.64%
	Discrimination w/ colour cue (within block TE)	12ms	4.04%	4.12%
	Discrimination w/ line cue (within block TE)	13ms	3.57%	3.62%
	Discrimination w/ colour cue (between block TE)	83ms*	2.86%	2.46%
	Discrimination w/ line cue (between block TE)	93ms*	2.81%	2.46%
McCormick, Redden, Lawrence, and Klein (2017)	Mixed Signal Intensities: Intense (discrimination)	6ms	8%	7%
	Mixed Signal Intensities: Isointense (discrimination)	1ms	8%	10%
	Blocked Signal Intensities: Intense (discrimination)	9ms	7%	5%
	Blocked Signal Intensities: Isointense (discrimination)	3ms	6%	7%
McCormick, Redden, Lawrence, and Klein (2018)	Mixed Signal Intensity: Intense (detection)	14ms*	NA	NA
	Mixed Signal Intensity: Isointense (detection)	15ms*	NA	NA

Error rate is an important metric for understanding whether temporal attention is generating pure improvements to performance, or whether it is improving speed at the cost of accuracy. In spite of the underreporting, there is still evidence from a variety of alternative metrics that temporal attention improves both motor preparation and perception, depending on the demands of the task. In studies in which only a detection response is required, physiological measures display increases in only motor preparation (Coull and Nobre, 1998; Griffin, Miniussi, & Nobre, 2002; Correa, Lupianez, Tudela, 2005), whereas studies which require a perceptual discrimination display increases in both motor preparation and perceptual processing (Correa, Lupianez, Tudela, 2005; Davranche, Nazarian,Vidal, and Coull, 2011; Denison, Heeger, and Carrasco, 2017). Additionally, temporal cueing has been shown to increase fixation stability at the likely target interval, which is theorized to be a mechanism for improving perception (Denison, Yuval-Greenberg, and Carrasco, 2019). The allocation of perceptual resources at these specific time-points has been shown to produce a trade-off of perceptual clarity in the moments before and after the expected stimulus presentation (Denison, Heeger, and Carrasco, 2017). Temporal cueing effects have been found both within and cross-modalities in cue-target paradigms (Lange and Roder, 2006).

1.4 Revising the Kingstone Paradigm

Although there have been great strides in the last couple decades related to the study of temporal attention, there are sound criticisms of some of the standardized methodological decisions. In a review titled 'Temporal orienting and alerting: the same or different?' Weinbach and Henik outline how the Kingstone cueing paradigm is confounded by exogenous alerting (2012). As explained previously, temporal orienting cues tell participants the likely SOA in which a target will be presented, while additionally indicating that the SOA has begun, or indicating to participants to start their internal timers. These cues traditionally involve an increase in intensity, whether it is visual (brightness) or auditory (sound). As salient stimuli typically induce a reflexive alerting response, it is not possible to observe a pure effect of endogenous temporal cueing with this methodological design. McCormick et al (2018) designed a modified Kingstone cueing paradigm to address this issue. Participants were presented with the temporal letter cue at the beginning of the trial, instead of at the start of the indicated temporal interval, and this remained on the screen until the target was presented (2018). This cue, which was either an ‘S’ to indicate a ‘short’ interval (400ms), or an ‘L’ to indicate a ‘long’ interval (1600ms), informed participants of the likely SOA that the target could be presented. Then, after a random interval (between 2 and 10 seconds), an auditory signal was played to inform participants to ‘start their interval clocks’ to the cued interval. This signal used dichotic sound, which allowed for the comparison of intense and isointense signals. Intense signals, which increased in dB, represented a replication of the previous work in the field, whereas isointense signals provided a novel opportunity to study purely endogenous temporal orienting. This new design deconfounds the relationship between alerting and temporal orienting, and also between the temporal cues informing participants of the interval and acting as the signal (see Figure 4).

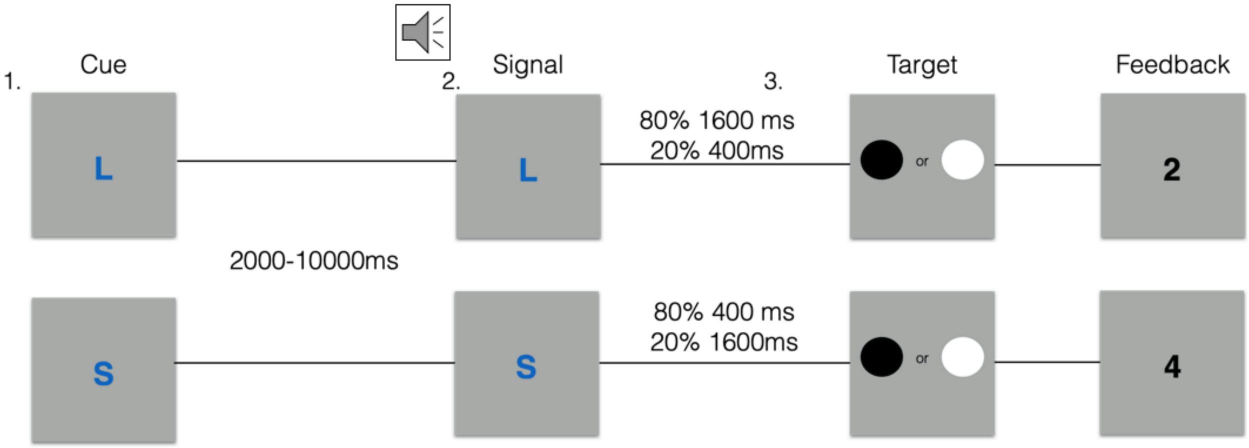

Figure 4. Design for McCormick et al. 2018. Section 1 of the figure displays the two different temporal cue types. These letters indicate whether a short (400ms) or long (1600ms) SOA will take place between the signal and target, with 80% accuracy. These cues remain on the screen for a 2000-10000 msec period. Then, a signal is played, either intense or isointense, which indicates participants should initiate their ‘internal timer’ to the indicated interval (section 2). Then, either the short or long SOA occurs, before the presentation of the target (section 3). Participants are then provided with RT feedback in the form of a single digit.

Two previous design attempts with this novel methodology were described in the introduction of McCormick et al (2018; see also McCormick, Redden, Lawrence, and Klein, 2017). In the first design, signals were intermixed within-blocks, so participants did not know whether they would be presented with an intense or isointense signal on a given trial. In this version, participants were required to discriminate between two possible targets. There were no temporal cueing effects in either signal condition (see Figure 5 'within-block'). This was perplexing, as the intense signal condition was a replication of the combined alerting type used by past temporal cueing studies. In experiment two, participants still made discrimination responses, but signals were presented between blocks. This meant that participants would know what signal they were going to receive for the whole block of trials. In this version, there was evidence of cueing effects in the intense signal condition, in which valid temporal cues generated faster RTs than invalid temporal cues, but there were no temporal cueing effects present in the isointense signalling condition (see Figure 5 'between-block'). This meant we replicated an analogous condition to the previous temporal research but failed to extend it with our purely endogenous condition.

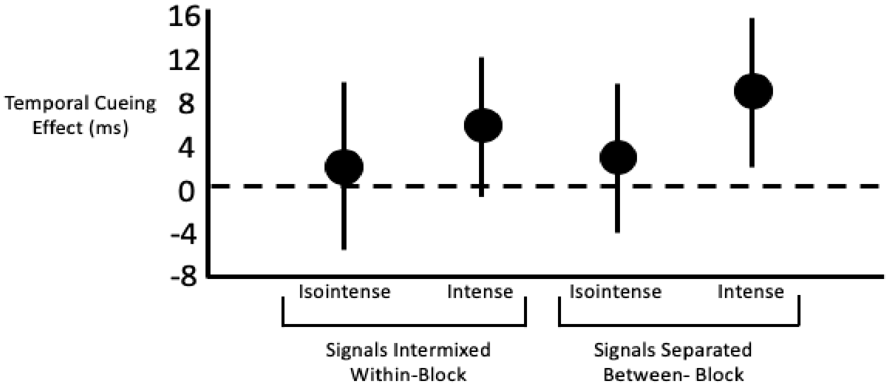

Figure 5. Redrawn from McCormick, Redden, Lawrence, and Klein, 2018. This displays the effect size of the temporal cueing effect (in ms) for each of the signalling conditions across two experiments. Error bars are 95% confidence intervals.

In an effort to understand these findings, we hypothesized that the amount of mental effort required to detect the isointense warning signal may have interfered with an observer's ability to effectively make use of the temporal cue. In conjunction with this, when in the block with both types of signals, participants are uncertain of what intensity the signal will be. This motivates them to enlist enough effort to detect an isointense signal, which results in non-significant cueing effects for both intensity conditions. This hypothesis is also strongly supported by observing cueing effects when there are only intense signals, and no effects when there are only isointense signals. Based on this hypothesis, we decided to replicate this experiment while reducing the cognitive load in an attempt to observe temporal cueing effects in both signalling conditions. In McCormick et al. (2018), participants completed a *detection* task where both signal types were intermixed within-block. Our intention of using a detection task (rather than discrimination which was used in the previous experiments) was to lower the cognitive demands associated with the primary response task in the expectation that with this lower demand, participants would have enough cognitive capacity to utilize the predictive temporal cues regardless of signal intensity. When analysing the result from this experiment, we were effectively able to produce a temporal cueing effect in both signalling conditions, presenting the first example of a temporal cueing effect in a purely endogenous condition. Additionally, using Sternberg's additive factors logic (1969), in which no interaction between both reaction time and variance of the data were observed, we were able to determine that these two forms of temporal attention, being generated by the intense and isointense signals, were affecting independent stages of processing (see Figure 6).

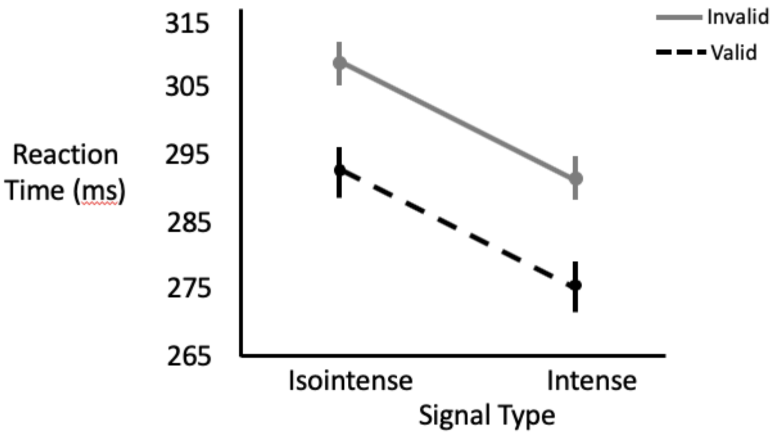

Figure 6. Recreated figure from McCormick et al., 2018. The additivity of these cueing RT effects across signal intensities, along with analysis that displays the additivity of RT variance, are evidence of the independence of these mechanisms.

This was the first paper to present the independence of these mechanisms in such a way, and also built off the work previously set forth by Lawrence and Klein in comparing these alerting mechanisms (2013).

Where this previous experiment was a detection task, as opposed to a discrimination task, there was only reaction time data to compare between signalling conditions. Although detection paradigms are used in temporal attention research and can be useful in generating knowledge about temporal mechanisms and performance, they do not allow for the measurement of all elements of performance. Accuracy is an important measure to be studying alongside reaction time within this paradigm, as we can see if temporal cueing generates genuine improvements to performance, or if there is an associated cost in one of these metrics. In the information processing theory of phasic alertness, it is outlined that alerting impacts the time in which a participant will respond to a stimulus but have no effect on the build-up of information (Posner, 1975). For this reason, accuracy measures are essential for properly studying the mechanisms of interest. The contrast of the speed-accuracy relationships of these two independent mechanisms is needed to properly categorize and utilize them. It would also allow for a comparison to the results from Lawrence and Klein, who showed different speed accuracy relationships between their different conditions (2013; Figure 3). They used a different design than the Kingstone paradigm, as participants were only ever cued to one interval during a block as opposed to flexibly switching trial-by-trial, so it is of interest whether the performance in the two conditions will align, or whether these generate a new pattern. Additionally, measuring accuracy during this temporal cueing task would potentially shed some light on whether temporal cueing is improving just the motor response, in which this mechanism allows for participants to respond faster, or whether it is also improving perception at the indicated interval, as has been predicted by past research (Denison, Heeger, and Carrasco, 2017).

For these reasons, it is clear that in order to make a proper comparison of performance between signalling conditions in this temporal cueing task, another component of this methodology must be simplified to allow for a discrimination task. In past research, the intuitiveness of the temporal cue has been a factor in obtaining a temporal cueing effect (Correa et al, 2004). The current project looks to implement the same procedure in an attempt to compare speed and accuracy performance between these two different signalling types, but while using more intuitive temporal cues.

CHAPTER 2 EXPERIMENT ONE

2.1 Prelude

This experiment uses McCormick et. al.'s modified Kingstone paradigm to compare performance between two forms of temporal cueing (2018). This involves using intense and isointense signals to inform participants of when to implement the temporal information provided by the cue. Instead of using letter cues to inform participants of when the target is likely to occur, we will be using two different line cues. The length of these lines will be representative of the temporal intervals. If a '--' cue is presented, this means that it is likely going to be a short SOA between the auditory signal and the target. If a '--------' cue is presented, this means that it is likely going to be a long SOA between the auditory signal and the target. These are scaled appropriately, as the 'short' SOA for this experiment is 400ms (two hyphens) and the 'long' SOA is 1600ms (eight hyphens). As these are considered to be more intuitive than the Kingstonian letter cues, we predict this will free up cognitive resources, produce temporal cueing effects in both signalling conditions, and allow for a comparison of speed and accuracy between these two groups. This means valid temporal cues will produce faster reaction times than invalid temporal cues in both signalling conditions. This would be the first-time temporal cueing effects were observed in a discrimination task using a purely endogenous temporal cueing manipulation. We also predicted that intense signals will produce faster responses than isointense signals due to their ability to elicit exogenous alerting. Importantly, this design will allow for the comparison of error rates, in which we expect the combined condition will produce less accurate responses compared to the purely endogenous condition. By addressing these hypotheses, we will be investigating the original unanswered questions associated with our two recent studies (McCormick et al. 2017; 2018). It will also give us the opportunity to compare our two signalling outcomes to Lawrence and Klein’s mapping of exogenous and endogenous alerting performance to see whether these results are applicable (2013).

2.2 Method

2.2.1 Pre-registration

This experiment was registered on the Open Science Framework (OSF) prior to the observation of any participant data. This registration includes description of hypotheses, methodology, and analysis plans. All associated project materials can be found on this project’s OSF page (https://osf.io/dexsm).

2.2.2 Participants

Forty-eight participants were run in this experiment in a computer laboratory. Data collection sessions involved a maximum of 10 participants at a time. Sessions were run until 40 or more participants met our trial count criterion. Prior research using this methodology has found detectable effects with 40 participants (McCormick et al., 2018; McCormick et al., 2017), which was our rationale for setting this criterion. All participants were undergraduate students at Dalhousie University. All participants had normal or corrected-to-normal vision and hearing. Further information on participants and the trial count criterion is provided in the results section.

2.2.3 Apparatus

This experiment was presented on ten 24-inch Apple monitors connected to a Mac Mini running OS X with a 2.66 GHz Intel Core 2 Duo processor and a NIVIDIA GeForce 9400 256 MB graphics card. A set of 10 headphone monitors (Sony MDR- 101LP) were used. The acceptable volume setting was four notches on the Mac volume interface. This volume was pre-set for participants, and they were instructed to inform the experimenter if it was too loud or quiet. If the experimenter was alerted that the volume was not appropriate, they made note of this and adjusted accordingly. Participants sat at a maximum distance of 102 cm from the screen. Game-pad controllers (Xbox 360 wired controllers; Microsoft Corp, 2006) were used by participants to make responses using the gradient triggers located under their index fingers.

2.2.4 Stimuli

Temporal cues, which could take the form of either a short line (--) or long line (--------) (.5 degrees of visual angle; DVA) were presented at the center of the screen until the presentation of the target. These cues were blue (RGB: 0, 0, 255) on a gray (RGB: 119, 119, 199) background. Targets took the form of circles (.5 DVA) that appeared at the center of the screen. Targets were either black (RGB: 0, 0, 0) or white (RGB: 255, 255, 255). Participants received on-screen feedback in the form of a single black or white digit (.5 DVA) after making their response. The number represented their reaction time on that trial to the 10th of a second, and the colour represents which of the two buttons they selected to respond to the target. Mono auditory white noise (generated by Python program) was constantly presented throughout a trial at a sampling frequency of 44100 Hz. Auditory warning signals were presented in the form of stereo white noise for a duration of 100 ms. In the ‘isointense’ warning signal condition, there was no change in intensity relative to the mono baseline. In the ‘intense’ warning signal condition, the ambient volume was doubled for this short duration.

2.2.5 Procedure

Participants were accurately instructed that the temporal information provided by cues would help optimize performance as the cues indicated with high probability (80%) whether the foreperiod between the auditory warning signal and the target would be short (400ms) or long

(1600ms). They were also informed that there were two types of auditory signal that would be played before the target, but that both are used to prepare for the upcoming target. An emphasis on speed was communicated to them. A practice block was conducted consisting of 40 trials that were not included in the analysis. Mono noise was presented in both ears continuously throughout the task. Trials began with a blue line which represents a probable 400 ms or 1,600 ms foreperiod between the later auditory warning signal and the presentation of the target, respectively. The temporal cue remained on-screen until the target was presented. The auditory warning signal was presented after a random exponential (i.e. non-aging) interval within the range of 2 to 6 seconds (mean = 4 s) to indicate the target was imminent. The auditory warning signal was either an intense or isointense shift from mono to stereo sound and was presented for a duration of 100 ms. Either 400 or 1,600 ms after the onset of this auditory signal, a black or white target was presented for either 1,000 ms, or until the participant responded. Discrimination responses were made by pressing one of the triggers on the gamepad. If it was a white circle target, participants were instructed to press the right trigger. If it was a black circle target, participants were instructed to press the left trigger[2]. Participants were instructed that they were required to press the response apparatus at least halfway down to register a response. If participants responded before the target was on the screen, then a message that read ‘Too Early!’ was presented in red (RGB: 255, 0, 0). If they failed to respond during this 1,000 ms window, then a message that read ‘Miss!’ was presented in red. If participants responded during the

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[2] Although target colour, which was confounded with responding hand (white=right), was not considered an important factor, it is worth noting that responses to white targets were about 15 ms faster than to black targets in both experiemnts. Because this was also true for the few left-handed participants that were collected (n=4), it is not believed that this is due to hand dominance. Instead, the relative salience of the white targets on the grey background was greater than that of the black targets. Importantly, the target factor did not interact with temporal cuing and its effect has been ignored.

correct window, they were presented with a single digit on the screen that represented their time in tenths of a ms. This experiment has 40 trials per block, with 12 blocks in total.

2.3 Results

2.3.1 Data Preprocessing

First, we used a number of recorded metrics to eliminate inappropriate responses from the reaction time data. Two-point three percent (571 trials) of pre-target responses were removed, along with <.1% (4 trials) of inter-trial responses. Six percent of trials (1622 trials) were eliminated because the participant pressed both triggers, and 4% (1007 trials) were eliminated for participants initiating one response and switching to another. Participants missed responses on 117 trials, which were removed. There were <.1% of trials (14 trials) in which participants did not reach the indicated threshold.

We then elected to use the relationship between reaction time and error rate to determine appropriate distribution cut-offs for this data-set. This procedure has been successfully used in prior research (Christie et al., 2015; McCormick et al., 2019), and provides a non-arbitrary procedure for excluding RTs that may not truly reflect the speeded information processing our task was designed to elicit. These cut-offs were made before performing any statistical analysis and were explained in our OSF registration (https://osf.io/dexsm). Inspection of the error rates for the faster end of the reaction time distribution will inform us of the fastest time in which participants were actually able to discriminate between targets, as we will only include data that indicates that participants were responding greater than chance (greater than 60% accuracy, with enough trials to believe that this accuracy is a valid representation of performance). For this data set, we binned reaction times in intervals of 50ms (0-50 ms, 50-100 ms, 100-150 ms, etc.) to compare accuracy and frequency of responses. At the faster end of responses, an increase in accuracy and frequency was observed at 200ms (150-200 ms: 59.1% accuracy, 22 trials; 200-250 ms: 65% accuracy, 207 trials). Breaking this further into 10ms bins, it was determined that 220 reflected a further improvement to accuracy (210-220 ms: 56% accuracy, 16 trials; 220-230 ms: 66% accuracy, 32 trials). This removed .4% of trials from the faster tail of the distribution (114 trials). For the slower end of the reaction time distribution, data was cut once a dip in accuracy was observed, as this represents an increase in non-task related behaviours (Christie et al., 2015. The same binning procedure was used, and a noticeable dip[3] in accuracy was observed at 800ms (750-800ms: 96% accuracy, 48 trials; 800-850ms: 89% accuracy). Splitting 800-850 into 10ms bins revealed that no further specificity was required. Cutting responses slower than 800ms eliminated .1% of trials from the slower end of the distribution (34 trials).

After these data trimming procedures, participants who did not contribute 70% 'useable' trials were excluded from analysis and replaced with another participant[4]. Participants were run with this exclusion principal until the desired sample of 40 participants was reached. Eight participants required replacement based on this criterion (ranging from 36.3 to 69.2 percent usable trials).

2.3.2 Statistical Tests

Results from 40 participants (15 male, 4 left-handed, mean age = 20.4 years) were included in statistical analysis. As noted in the Introduction, once the short SOA has expired without a target, performance on targets presented at the long SOA is confounded by the possibility that temporal

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[3] The numerical value that determines what a 'dip' is was not set a priori and was determined using visual inspection of the reaction time bins.

[4] This value deviates from the 75% useable trials indicated in the OSF preregistration. Seven of the 40 participants fall between the 70% to 75% range (70, 70, 71, 72, 73, 73, 74), but replacement was not possible due to Covid-19 restrictions.

reorienting will obviate the cueing manipulation. Therefore, our primary analyses will focus on response times to targets presented at the short SOA, as is typical in the literature.

Linear mixed-effect models were used to evaluate the presence of our effects of interest for reaction time (RT). Reaction times were inverted (1/RT) to normalize the distribution. Comparisons between an unrestricted model, which includes the main effect and all lower order effects, and a restricted model, which includes the same lower order effects, is used to see if the evidence accumulated supports the effect or the null. These comparisons are obtained via likelihood ratios, with Akaike's information criterion (AIC) corrections to account for the discrepancy of complexity between models (Akaike, 1974). The presented ratios are in log-base-2, so that positive values can be interpreted as evidence for the effect, and negative values are evidence for the null. The absolute value of the ratio is indicative of the confidence in the model. A relevant and comprehensive explanation of this statistical method can be found in the statistical tools section of Lawrence and Klein (2013). As a general guideline, a ratio of 8 can be considered 'pretty strong' evidence, while 32 is considered 'strong', although this is meant to be used as a continuous metric (Royall, 1977).

2.3.3 Results and Interpretation

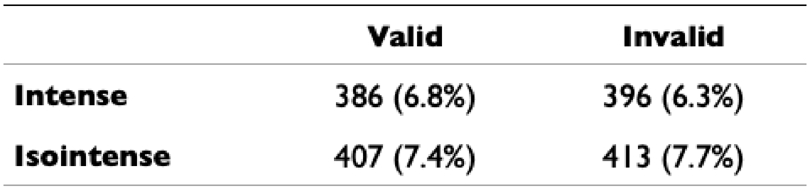
Table 2

The short SOA Likelihood Ratios for the inverse of reaction time (1/RT) and error rate (Error) for experiment one. Values are bits of evidence, as calculated via Log-Base-2 AIC Corrected Likelihood Ratios.

Condition	1/RT	Error
Cue Validity	34.93	-2.88
Signal Intensity	224.70	0.88
Validity * Intensity	0.56	-2.39

Table 3

Mean Reaction Times (and ER) for the short SOA



	Valid	**Invalid**
Intense	386 (6.8%)	396 (6.3%)
Isointense	407 (7.4%)	413 (7.7%)

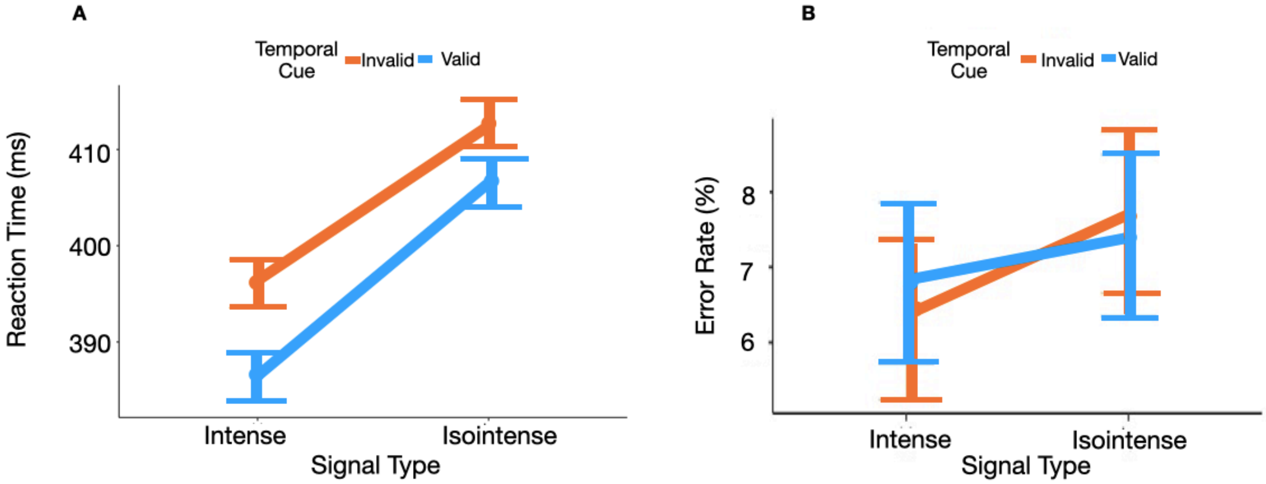


Figure 7: Reaction Time (A) and Error Rate (B) data for the short SOA in experiment one. Signal intensity conditions are separated on the X axis, while the temporal cue validity is split between the orange (invalid) and blue (valid) lines.

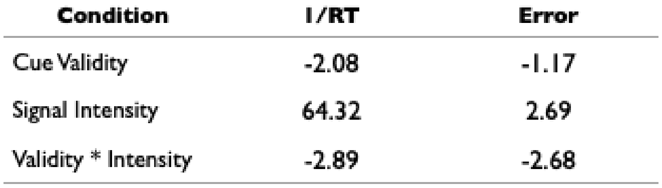
As mentioned, this analysis is only on the short SOA data. As hypothesized, there was strong evidence for an effect of cue validity on reaction time in this experiment. Participants were faster when presented with valid temporal information in comparison to invalid temporal information (see Figure 7). This strongly indicates the presence of temporal cueing effects. There was also very strong evidence of an effect of signal intensity, in which intense signals produced faster participant responses in comparison to isointense signals (see Figure 7). As previously observed in past experiments (McCormick, Redden, Lawrence, and Klein, 2018), there is no interaction between validity and intensity.

For error rate, a generalized linear mixed-effect model was run with a binomial distribution. There was no evidence for any main effects or interactions, contrary to what was predicted based on past research (Lawrence and Klein, 2013), but conforming to what has been observed for past intense signal research (see Table 1).

2.3.4 Additional Analysis

Table 4

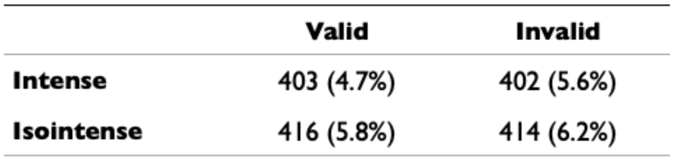
The long SOA Likelihood Ratios for the inverse of reaction time (1/RT) and error rate (Error) for experiment one. Values are bits of evidence, as calculated via Log-Base-2 AIC Corrected Likelihood Ratios.



Condition	1/RT	Error
Cue Validity	-2.08	-1.17
Signal Intensity	64.32	2.69
Validity * Intensity	-2.89	-2.68

Table 5

Mean Reaction Times (and ER) for the long SOA for experiment one



	Valid	Invalid
Intense	403 (4.7%)	402 (5.6%)
Isointense	416 (5.8%)	414 (6.2%)

Likelihood ratios were also calculated for the ‘less analytic’ long SOA. They are considered less analytic because of a participant’s ability to re-orient their attention to the appropriate SOA on an invalid short cue trial. The likelihood ratio for cue validity backs this concept up, as there is no evidence of a valid temporal cue benefit. There is evidence of an effect of signal intensity, in which intense signals produce faster responses than isointense signals. There is no evidence of an effect of the various conditions on error rate.

An additional analysis was run on error rate in which reaction time cut-offs were not conducted, and error rate included double-presses, switch responses, and responses which did not reach the indicated threshold. It did not generate evidence of an effect of signal, cue validity, or an interaction between those two factors, so the outcomes were the same as the planned error analysis.

2.4 Discussion

The objective of this experiment was to observe temporal cueing effects in both the combined (intense) and purely endogenous (isointense) signalling conditions in a discrimination task so that we could compare speed and accuracy data. Prior research displayed temporal cueing effects in a detection task, as it is less cognitively demanding, but this did not allow for a comparison of accuracy (McCormick et al., 2018). The manipulation of interest in this experiment was the use of a more intuitive cue to offset cognitive effort and allow for participants to show a cuing effect in a discrimination task. As indicated in the above section, we were successful in generating temporal cueing effects in both the combined condition and, for the first time in this literature, a purely endogenous condition. This is further evidence that temporal cueing is mitigated by increased mental effort (Correa et al., 2004; de la Rosa, Sanabria, Capizzi, & Correa, 2012; McCormick et al., 2018), as a previous attempt with an identical methodological structure, but a less intuitive cue, was unsuccessful (McCormick, Redden, Lawrence, and Klein, 2017). Now that it has been shown that temporal cueing effects are possible with both forms of temporal attention in a discrimination task, a comparison of the relationship between speed and accuracy is possible to see exactly how they may be differently impacting performance.

However, this experiment joins the long lineage of temporal attention research with no reliable effect of error rate based on temporal cue validity (see Table 1). Even with our use of appropriate statistical modeling of the binomial error rate distribution, we find no difference between valid and invalid temporal cues. If this were the true effect, it would potentially support the prior research indicating that temporal attention is merely motor preparation, as perception of the target is not improved in the valid cue condition, or negatively impacted in the invalid cue condition. The only difference is participants are faster to register their answers on validly cued trials. However, this runs counter to prior research that has studied temporal attention using other methodological tools, displaying improvement in perception at anticipated intervals, and a cost in perception both before, and after, these intervals (Denison, Yuval-Greenberg, and Carrasco, 2019; Denison, Heeger, and Carrasco, 2017). While we accomplished our goal of observing temporal cueing effects in both purely endogenous and combined temporal attention through offsetting cognitive load, we are left with an inconclusive picture of how it affects other areas of performance that are important for understanding the mechanism. There was also a failure to find the distinctions in speed/accuracy performance that Lawrence and Klein reported between the two forms of temporal attention. If there are truly no effects on error rate in both signalling conditions, this means that combined temporal attention is superior, as participants are faster with no cost to accuracy. In contrast, Lawrence and Klein found that the purely endogenous condition improved both speed and accuracy, while the combined condition generated a speed-accuracy trade-off (2013). Although our task was different than Lawrence and Klein's, where ours involved temporal cues while theirs used fixed temporal intervals, this suggests limits to the generalizability of their findings. However, when looking at the speed and accuracy results across the diverse spectrum of SOAs they tested, it appears that our analytic SOA of 400ms falls within a time-course that may be less sensitive to differences between the two forms (see figure 8, red line).

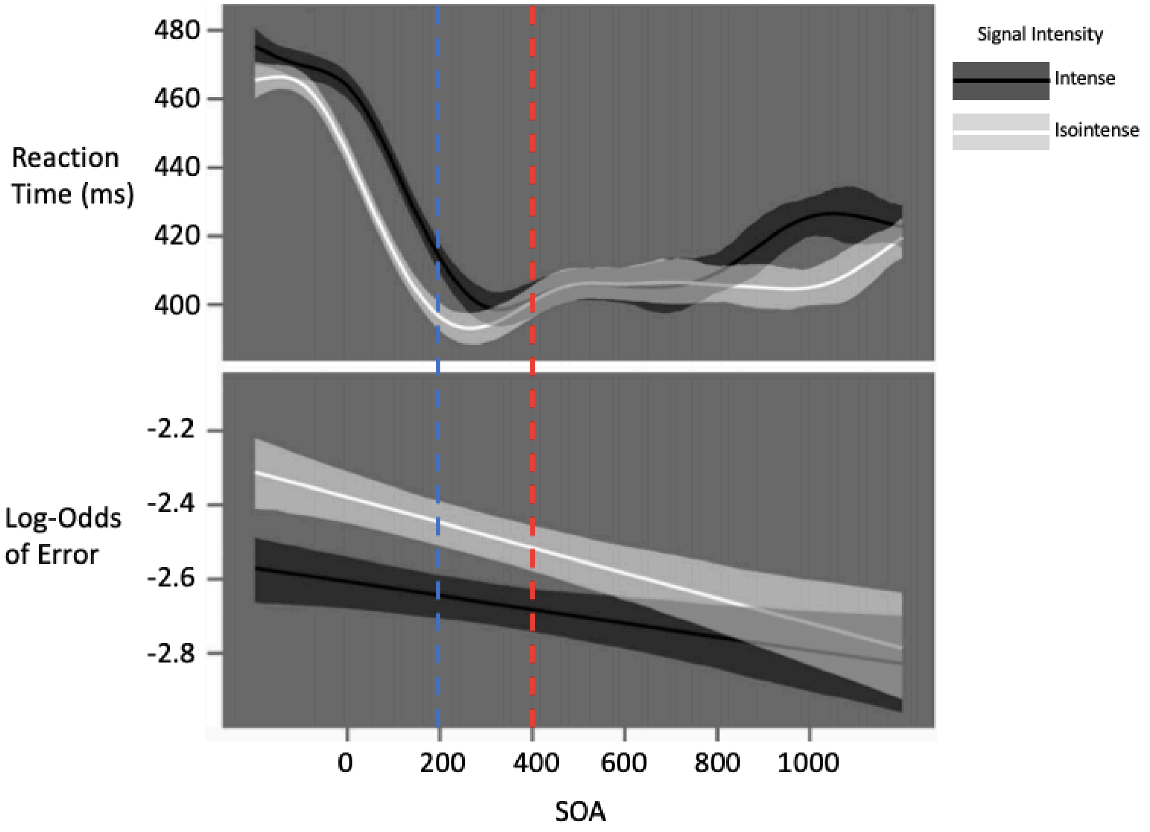


Figure 8: A modified figure from Lawrence and Klein, 2013. The top half shows RT comparisons between intensity conditions, while the bottom shows error differences. The red line represents where E1's short SOA would fall on this figure. The blue line represents the modified short SOA used in E2.

Whereas our task was different than theirs and could therefore represent differences in the time-course of performance, it is worth considering that using a shorter SOA could better lend to performance comparisons between these two intensity conditions. So, with this is consideration, we decided to run a second experiment with faster SOAs to see how this may potentially generate differences in both reaction time and error rate performance.

CHAPTER 3 EXPERIMENT TWO

3.1 Prelude

This experiment aims to observe the anticipated error rate differences in a temporal cueing task by replicating experiment one but using 200 and 1400ms SOAs instead of 400 and 1600ms. This will shift us earlier along Lawrence and Klein's time-course in the above figure (figure 8, blue line). In past temporal cueing studies, temporal cueing effects have been observed as early as 200ms in detection tasks, but not in the discrimination task (Griffin, Miniussi, and Nobre, 2001). The study that attempted, but failed, to obtain temporal cueing effects in the discrimination task, however, used temporal cues that were less intuitive than ours (two circle sizes for short and long). Additionally, this 2001 study only generally cued 'short' SOAs, as the target could appear at a multitude of intervals (potentially reflecting more of a hazard sensitivity than a temporal association). As experiment one was able to alleviate enough cognitive demand to generate temporal cueing effects where they had not been previous found, we are hopeful that our methodological difference will allow for us to see temporal cueing effects in both signalling conditions. If so, we anticipate that the intense signalling condition will generate improved response speed while decreasing accuracy for temporal cues, while the isointense signalling condition will improve both speed and accuracy. The intense condition should be overall faster than the isointense condition as well, and there should be an overall effect of temporal cues in which validly cued trials are faster than invalidly cued trials.

3.2 Methods

3.2.1 Design

Experiment two follows the same procedure as experiment one, except that it changes the SOAs from 400ms and 1600ms for short and long to 200 and 1400ms. All other procedures and equipment are identical.

3.2.2 Registration

This experiment was registered on the Open Science Framework (OSF) prior to the observation of any participant data. This involved description of hypotheses, methodology, and analysis plans. All associated project materials can be found on this project's OSF page (https://osf.io/b28fs).

3.2.3 Participants

Forty-four participants were run in this experiment in a computer laboratory. Data collection sessions involved a maximum of 10 participants at a time. Sessions were run until 40 participants met our trial count criterion. Prior research using this methodology has found reliable effects with 40 participants, which was our rationale for setting this criterion. All participants were undergraduate students at Dalhousie University. All participants had normal or corrected-to-normal vision and hearing.

3.3 Results

3.3.1 Data Preprocessing

We used the same metrics to eliminate inappropriate responses from the reaction time data as we did in experiment one. One-point one percent (220 trials) of pre-target responses were removed, along with <.1% (7 trials) of inter-trial responses. 4.6% of trials (948 trials) were eliminated because the participant pressed both triggers, and 2.1% (423 trials) were eliminated for participants initiating one response and switching to another. Participants did not respond during 67 trials, which were removed from analysis.

We used the same reaction time cut-off procedure as in experiment one. At the faster end of responses, an increase in accuracy and frequency was observed at 250ms (200-250 ms: 59% accuracy, 78 trials; 250-300ms: 88.4% accuracy, 1140 trials). Breaking this further into 10ms bins, it was determined that 250 reflected the best cut-off for performance within the five-bin comparison (250-260ms: 81% accuracy, 76 trials; 260-270ms: 88% accuracy, 131 trials). This removed .5% of trials (98 trials). For the slower end of the reaction time distribution, data was cut once a dip in accuracy was observed, as this represents an increase in non-task related behaviours. The same binning procedure was used, and a dip was observed at 950ms (900-950ms: 100% accuracy, 15 trials; 950-1000ms: 78% accuracy, 9 trials). This eliminated <.1% of trials (9 trials).

After these data trimming procedures, participants who did not contribute 70% 'useable' trials were excluded from analysis and replaced with another participant[5]. This was done until the desired sample of 40 participants was reached. This value was decided beforehand and is in the OSF preregistration. Four participants required replacement based on this criterion (ranging from 24% to 66% percent usable trials).

3.3.2 Results and Interpretation

Results from 40 participants (5 male, 3 left-handed, mean age = 19.5 years) were included in statistical analysis. Our primary analyses will focus on response times to targets presented at the short SOA. Linear mixed-effect models were used for the transformed RTs (1/RT) for

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[5] This value deviates from the 75% useable trials indicated in the OSF preregistration. Three participants fall between the 70% to 75% range (70, 72, 72), but replacement was not possible due to Covid-19 restrictions.

experiment two in the same capacity as experiment one. AIC likelihood ratios were compared, and the ratios are presented in log-base-2.

Table 6

The short SOA Likelihood Ratios for the inverse of reaction time (1/RT) and error rate (Error) for experiment two.Values are bits of evidence, as calculated via Log-Base-2 AIC Corrected Likelihood Ratios.

Condition	**1/RT**	**Error**
Cue Validity	10.58	-2.49
Signal Intensity	293.62	-2.77
Validity * Intensity	0.06	-2.63

Table 7

Mean Reaction Times (and ER) for the short SOA for experiment two

	Valid	**Invalid**
Intense	399 (6.0%)	408 (6.6%)
Isointense	422 (6.3%)	425 (6.4%)

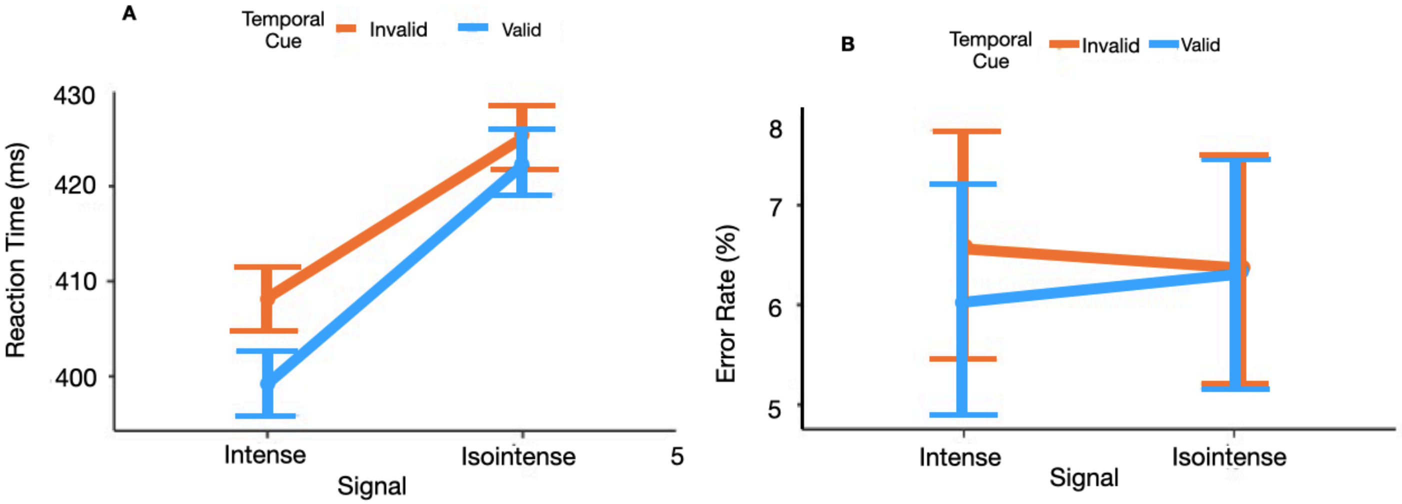

Figure 9: mean RT (left) and ER (right) for the short SOA in experiment two. Signal intensity is indicated on the x axis, while the temporal cue validity is split between the orange (invalid) and blue (valid) lines.

There is evidence of a benefit of temporal cueing in this task, with valid temporal cues generating faster responses than invalid temporal cues (figure 9). However, visual inspection of this data seems to indicate that this cueing effect is driven by responses in the intense signalling condition. This is worth consideration and reflects trends observed in past experiments (Capizzi, Sanabria, and Correa, 2012, McCormick et al., 2018). With this said, there is no evidence of an interaction between signal intensity and temporal cue validity. There is strong evidence of signal intensity impacting reaction time performance, with intense signals generating faster responses than isointense signals.

As was the case in experiment one, there was no evidence of any effect of our conditions on error rate when comparing generalized linear mixed-effect models with binomial distributions, counter to our prior predictions.

3.3.3 Additional Analysis

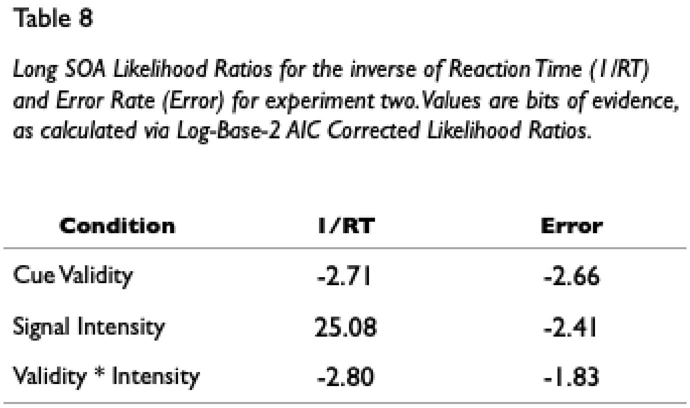

Table 8

Long SOA Likelihood Ratios for the inverse of Reaction Time (1/RT) and Error Rate (Error) for experiment two. Values are bits of evidence, as calculated via Log-Base-2 AIC Corrected Likelihood Ratios.

Condition	1/RT	Error
Cue Validity	-2.71	-2.66
Signal Intensity	25.08	-2.41
Validity * Intensity	-2.80	-1.83

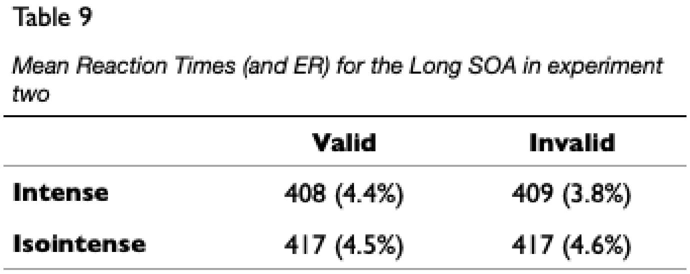

Table 9

Mean Reaction Times (and ER) for the Long SOA in experiment two

	Valid	Invalid
Intense	408 (4.4%)	409 (3.8%)
Isointense	417 (4.5%)	417 (4.6%)

We compared our conditions at the long SOA. As with experiment one, there was evidence of an effect of signal intensity on reaction time, in which intense signals produced faster reaction times than isointense signals, but no other effects.

An additional analysis was run on error rate in which reaction time cut-offs were not implemented, and error rate included double-presses and switch responses. It did not generate evidence of an effect of signal, cue validity, or an interaction between those two factors, so the outcomes were the same as the planned error analysis.

3.4 Discussion

The aim of this experiment was to try to compare and contrast how two forms of temporal attention would differently impact reaction time and error rate using two novel SOAs. Due to experiment one's failure to observe said differences in error rate, we thought presenting the target in a shorter temporal proximity to the signal may generate the expected result. However, there were still no significant error effects, and additionally the isointense signal condition no longer produced a temporal cueing effect. As mentioned, this reflects the pattern of results in McCormick et al. (2017), in which increased task difficulty reduces the chance of observing temporal cueing effects, especially in this purely endogenous condition. Although this experiment has the same error rate as experiment one, the reaction times are slower, indicating that it was potentially more difficult. This could also be because it takes a bit longer to detect an isointense signal. When the SOA is shortened from 400 to 200ms, participants do not have enough time to actually prepare for the presentation of the target.

Although this outcome restricts our ability to compare results between the combined and pure endogenous temporal attention conditions as anticipated, this experiment was successful in generating a temporal cueing effect at the shortest SOA of any discrimination-task study to date. This again reinforces the influence of task demand on temporal attention, as our methodology of using an intuitive cue was able to off-set enough demand to generate an effect where it was not found previously (Griffin, Miniussi, and Nobre, 2001), and show the speed that temporal attention can be oriented. It is also worth briefly mentioning that there was more evidence of an effect of signal intensity in this experiment in comparison to experiment one, due to the shortened period between the signal and the presentation of the target. This is the influence of exogenous alerting mechanisms, as they typically peak around this time-course and slowly taper off in the period following (McCormick et al., 2019; Posner, Klein, Summers, and Buggie, 1973).

CHAPTER 4 GENERAL DISCUSSION

The comprehensive goal of this thesis was to compare purely endogenous temporal attention and a combined form of endogenous and exogenous temporal attention. Specifically, we aimed to expand upon the previous work done in this field to see how performance differed between these two conditions when measuring both speed and accuracy. When focusing on speed as a metric, we had success with our methodological manipulation that alleviated cognitive load and allowed for temporal cueing effects to be observed equally for both forms of temporal attention when the SOA was 400ms. This was the first time this effect has been found for the purely endogenous condition in a discrimination task, and the second time for any purely endogenous temporal cueing study (next to McCormick et al., 2018). When this SOA was shifted to 200ms, there was evidence that participants were able successfully orient their temporal attention when provided with an intense signal (combined temporal attention), but not when provided with an isointense signal (purely endogenous temporal attention). While this shortened length of time could simply represent an increase in task difficulty, similar to results observed in past temporal cueing studies (Correa et al., 2004; de la Rosa, Sanabria, Capizzi, & Correa, 2012; McCormick et al., 2018), it could also be the delay in detection of the isointense signal, leaving no time in the short 200ms to actually implement the internal timer (Santee and Kohfeld, 1977).

Considering how important cognitive load and task demands continue to be, there are a few potential options for making this task easier to observe reaction time temporal cueing effects in a purely endogenous condition at 200ms, while still using the modified Kingstone cueing paradigm. One option is inspired by a previous attempt to find temporal cueing effects in a discrimination task (McCormick et al., 2017). When using a less intuitive temporal cue (S and L), previous work intermixed the two different signal types and found no temporal cueing effects in either intensity condition. By separating these signal types between-block, meaning participants only receive one type of signal per set of trials, participants were able to prepare appropriately for the anticipated signal on each trial. This change allowed us to observe effects in at least one of the conditions where it was not present in the mixed within-block design (combined temporal attention). If we were to rerun experiment two with signal types presented between-blocks, as opposed to mixed within-block, this would increase our likelihood of seeing the desired temporal cueing effect in both temporal attention conditions. Another possible solution would be separating the different SOAs between blocks, as was done in Correa et al. (2004). This means that on a given block, targets are presented at one interval 80% of the time, and the alternative interval 20% of the time. While this manipulation produces significantly larger temporal cueing effects (see Table 1), this is less like temporal cueing and more like hazard sensitivity. This still may be worth exploring purely out of interest of how participants can utilize the novel isointense signal in these temporal performance tasks, but will not inform us as much on the mechanism of temporal cueing that was of interest in the current paper.

There is a caveat to these proposed follow-up experiments: as we have seen from experiment one, the presence of a temporal cueing effect does not guarantee that we will have an analytic error rate to compare across the two forms of temporal attention. Throughout our lab's study of temporal attention, we have not observed the expected contrasts in speed-accuracy performance. Furthermore, we also do not see differences in error rate based on cue validity. Even if one were to speculate that this performance represents motor preparation via alerting instead of the anticipated improvements to both motor preparation and perception, we should still expect to see decreases in accuracy when RT decreases (Posner, Klein, Summers, and Buggie, 1973). However, past studies have found that temporal cueing improves both of these dimensions, motor preparation (Coull and Nobre, 1998; Griffin, Miniussi, & Nobre, 2002; Correa, Lupianez, Tudela, 2005) and perception (Correa, Lupianez, Tudela, 2005; Davranche, Nazarian,Vidal, and Coull, 2011; Denison, Heeger, and Carrasco, 2017), depending on their utility to accurately completing a task. This may suggest that we should try moving away from a simple two alternative forced choice task and implement a more diverse set of tools to study how these two forms of temporal attention are impacting performance. One of the alternatives that may be well suited for studying accuracy and perceptual differences in temporal cueing is target colours discrimination, where the colour is selected from a continuous colour wheel (Zhang and Luck, 2008). This target could be presented for a short interval, either at the cued or uncued time-point. At the end of each trial, participants would have to select the colour which they believe was presented on a colour wheel. This provides a continuous metric which allows for the separate analysis of probability and fidelity. Probability is whether the participant had encoded that stimulus, and fidelity is the detail of that perception. One would imagine that probability could be impacted by temporal cue validity, as if a participant is temporally focused at another interval they may miss the target stimuli, but also that fidelity would be impacted by the two different forms of temporal attention, as accuracy differs in past studies (Lawrence and Klein, 2013). Having the target appear only briefly would also likely increase a participant's reliance on temporal cues as well, as there is more cost to performance by not paying attention when they appear. This may improve the reliance and size of the cueing effects. Additionally, EEG could also display contrasts between purely endogenous and combined temporal attention. A specific event-related potential called Contingent Negative Variation (CNV) has been found in relation to temporal attention (Walter et al., 1964). CNV has two separate components that differently impact performance: an early component, sometimes called the orienting wave, or O wave, which is associated with perceptual preparation, and an expectancy wave, or E wave, which is associated with motor preparation (Correa, Lupianez, Madrid, and Tudela, 2006). We anticipate that the time-courses and amplitudes could potentially be different for these two forms of temporal attention, as the combined form involves exogenous alerting and faster reaction times.

Using a diverse set of tools to compare these two forms of temporal attention will help generate a more comprehensive understanding on how these mechanisms differently operate, and how they impact performance on cognitive tasks. This will then later on contribute to how one may choose to elicit these two forms differently in an applied context, as we anticipate there will be benefits and costs to the use of each. As temporally-sensitive warning systems will remain an important component of safety systems through the new age of automated interfaces, in self-driving cars or for autopilot on planes or sea-vessels, it is important that we understand which attentional mechanism we wish to have active in a particular scenario to have the best performance outcome. There is still much work left to do in the temporal domain of attention, and researchers must carefully consider the tools and methodologies they are using to ensure they are not interfering with a participant’s ability to use these mechanisms of temporal attention.

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