Duration Magnitude and Memory Resource Demand

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Abstract
Whether duration magnitude modulates the cognitive resources required to represent that duration in memory is a fundamental question about the cognitive architecture of interval timing. The amplitudes of the Event-Related Potential (ERP) Slow Waves (SWs) elicited when participants maintain representations of different durations (e.g., 1500 versus 3000 ms) in memory may provide an answer to this question because increased positive SWs have been associated with increased working memory demands in studies of verbal and spatial memory. Here, participants judged whether a probe stimulus (S2) was the same duration as the preceding sample stimulus (S1). SWs recorded during a 2 s delay interval between S1 and S2 presentation were significantly more positive in the 3000 ms condition than in the 1500 ms condition, particularly at frontal-central electrode locations. This result suggests that the magnitude of the duration to be remembered influences the cognitive resources required to represent that duration in working memory.

Key Words: interval-timing, electrophysiology, event-related potential, slow waves, time perception

Introduction
A fundamental question about the cognitive and neural architecture of interval timing is whether the cognitive resources required to represent duration in memory depend on duration magnitude (i.e. length). Specifically, does a longer duration require more cognitive resources for memory representation than does a relatively shorter duration? Indeed, a defining difference between many current models of interval timing is whether the proposed cognitive and neural structure implies magnitude dependent resource use or magnitude independent resource use.

For example, the information-processing timing model of Scalar Expectancy Theory (SET, Gibbon, 1977, 1991a, 1991b; Gibbon et al., 1984) implies greater resource use for longer durations. The model comprises three stages: clock, memory, and decision. The clock consists of a pacemaker that emits pulses and a switch that, when closed, permits the pulses to reach an accumulator. The accumulator pulse count grows as a linear function of objective time (see Allan, 1998 for review). The accumulator pulse count can also be represented within a working memory buffer. For example, when there is a retention interval before a decision can be made the memory of the duration must be maintained across the delay. Durations that are biologically significant are stored in reference memory. According to the model, temporal decisions rely upon comparison of the currently elapsing duration, sampled either from the accumulator
Evidence from event-related potential (ERP) studies is consistent with a segregation of internal clock components. The amplitude and peak latency of the contingent negative variation (CNV, Walters et al., 1964), a negative going ERP waveform observed at frontal-central electrode locations, have been implicated as markers of accumulator-like activities (Bendixen et al., 2005; Macar et al., 1999; Pfeuty et al., 2005). For instance, Pfeuty et al. (2003) found that the left and medial frontal CNV amplitude increased until the memorized standard duration had elapsed, whereas the right CNV amplitude continued to increase for as long as the stimulus was present, even when the stimulus duration exceeded the memorized standard duration. The authors interpreted this result as indicating that the left and medial frontal CNV reflects a temporal accumulation process and/or subvocal rehearsal, whereas the right hemisphere CNV reflects anticipatory attention allocated to the end of the stimulus interval.

While considerable research has been conducted to clarify the relationship between the CNV and encoding of temporal information, the maintenance of the interval duration in working memory has been less well examined. The pacemaker-accumulator model outlined above suggests that representing longer durations would require more cognitive resources. Our interest here, therefore, is in the use of ERP slow waves (SWs) as an indicator of memory resource demand. For example, Bosch et al. (2001) examined SWs during visual and spatial memory retention in an S1 – S2 paradigm. In this paradigm, the participant was presented with a memory stimulus (S1), which had to be held in memory across a retention interval and compared to a second stimulus (S2). Bosch et al. (2001) asked participants to remember both the identity and the spatial location of the S1 at the beginning of each trial. A cue presented early in the retention interval indicated whether participants had to retain visual, verbal (name of the visual stimulus), or spatial information for a subsequent same/different decision. Relative to a perceptual control condition that did not make memory demands, the visual memory condition elicited negative frontal slow waves, and the spatial memory condition elicited posterior positive slow waves. The authors interpreted these slow waves as reflecting maintenance of object and spatial representations in working memory and goal-related attention.

Mental workload also impacts tonic, relatively long lasting, slow waves (for a review see Rösler et al., 1997). For example, McEvoy et al. (1998) manipulated working memory load in both spatial and verbal conditions of a continuous n-back letter-matching task. Participants had to judge whether the current stimulus was the same as that presented on a previous trial, either 1-back (low memory load) or 3-back (high memory load). Each trial began with a cue and was followed by the letter stimulus. The authors found a frontal positive SW that was more positive for the higher memory load condition from about 400 to 1300 ms following stimulus presentation and a parietal negative SW that was more negative for the higher memory load condition from about 400 to 1400 ms following stimulus presentation.

These results suggest that SW amplitude reflects memory load, but it also appears that memory related slow waves can manifest as either a positive or negative wave at different scalp locations and that task type also influences slow wave polarity (Bosch et al., 2001). So, although in the McEvoy et al. (1998) study higher load corresponded to an increase in positive slow wave amplitude (i.e. more positive) at frontal and central electrode sites and an increase in negative slow wave amplitude (i.e. more negative) at parietal electrode sites, the same pattern may not hold in other paradigms.

Assuming slow waves reflect memory demands, whether longer durations require more cognitive resources for representation in memory can be examined using a temporal version of the S1-S2 paradigm. In this paradigm, S1 and S2 durations of either the same or different magnitude, are presented successively with an interleaved retention delay (e.g., Schubotz & Friederici, 1997; Häßig et al., 1998; Macar & Vidal, 2004; Monfort & Pouthas, 2003; Schubotz & Friederici, 1997). Therefore, SW amplitude differences during the retention
interval for different duration S1 stimuli would suggest differential memory demands.

Although the impact of duration magnitude on SW response during the S1-S2 delay has not, to our knowledge, been specifically examined previously, several authors have used ERPs in conjunction with S1-S2 paradigms to investigate the representation of duration information in memory. For example, Schubotz and Friederici (1997) compared ERP topographical distributions when participants performed visual and auditory temporal and non-temporal tasks. They examined the ERP waveforms elicited between the onset of an S1, ranging in duration from 275 to 650 ms, to the onset of the S2. They reported a widespread positive slow wave, focused over central-parietal electrode sites, during the later stage of the retention delay (i.e. from 1200 ms post S1 onset to S2 onset) that was present for temporal (auditory) tasks, but not non-temporal tasks. The authors suggested that this SW reflected inhibitory processes required to maintain the correct temporal information without further interference of new input from the same modality. In addition, there was a negativity at frontal-central electrode sites (0 to 1200 ms) in both the visual and auditory timing tasks before the late prolonged positivity, which the authors claimed reflected duration encoding and maintenance processes. These SW results suggest an interplay between temporal encoding, memory maintenance, and central executive processes (inhibition).

More directly relevant to the approach taken here is an experiment by Monfort and Pouthas (2003). These authors explored the relationship between slow waves and temporal processing with a hybrid S1-S2 paradigm in which the S2 presentation was split into two parts on some trials (Gap trials). During these Gap Trials, the first half of the S2 preceded the retention delay interval and the second half of the S2 followed the retention interval. Thus, participants had to retain both the S1 duration and the first half of the S2 duration during the delay. They found a frontally distributed positive slow wave during the retention delay. This slow wave was significantly more positive at middle frontal electrode sites during the Gap trials as compared to No Gap trials.

Taken together, these interval-timing experiments suggest that the amount of temporal information modulates the amplitude of the SWs, but neither experiment strictly examined whether duration magnitude was the critical factor. For example, in Monfort and Pouthas (2003) participants had to keep the representations of the S1 and initial part of the S2 distinct in order to complete the task successfully. Therefore, it is unclear whether the SW difference was due to keeping two durations separate in memory across the delay interval, to the duration magnitude, or to some combination of the two factors.

Here, we limited the memory load manipulation to the length of the S1 duration. On each trial, a visually demarcated S1 was followed, after a 2 s delay, by a visually demarcated S2. Upon S2 offset, the participant indicated whether the S2 duration was the same as or different from the S1 duration. This S1-S2 procedure permits comparison of the SW amplitudes elicited during the delay between S1 and S2 for various S1 duration lengths. Significant differences in SW amplitudes elicited by different duration S1 stimuli would indicate differential allocation of cognitive resources in representing durations of different magnitudes.

**Method**

**Participants**

Twenty-five students (six males) from the Chinese University of Hong Kong participated in this study for either course credit or monetary payment. All were right-handed, aged between 19 and 25, and had normal or corrected to normal vision.

**Procedure**

Stimuli were blue and red squares (3.5 x 3.5 cm) presented against a white background and at the center of a 17” LCD computer screen. The distance between the participant and the screen was about 60 cm, thus each stimulus spanned a visual angle of about four degrees. An S1-S2 procedure was adopted. The S1 was demarcated by a blue square that initially appeared for 50 ms and then reappeared for another 50 ms presentation either 400 ms, 1400 ms, or 2900 ms later. Therefore, the S1 duration on a given trial was 500, 1500, or 3000 ms, from onset to offset of the two squares. A 500 ms fixation cross preceded each S1 to indicate that the trial had started. The delay between the fixation
cross onset and the onset of S1 (i.e. onset of the first blue square) was manipulated so that the duration between fixation cross onset and the offset of S1 (onset of the second blue square) was the same across all three conditions. Consequently, the delay from fixation cross offset to S1 onset was 3000 ms, 2000 ms and 500 ms for the 500 ms, 1500 ms and 3000 ms S1 conditions, respectively. This was done to rule out different attention demands preceding the S1-S2 delay as a potential explanation of any condition differences by ensuring that the attentional demands preceding the S1-S2 delay were as similar as possible across conditions.

S1 offset was followed by a constant 2 s inter-stimulus interval (ISI). The S2 was similar in structure to S1 in that it was bracketed by two squares each presented for 50 ms, but the squares were colored red to help distinguish the S2 from the S1. After S2 offset, the words “same/different” appeared on the screen for 1500 ms and participants indicated via key pad whether the S2 duration was the same or different from the S1 duration. Response hand to same/different assignment was counterbalanced across participants. Feedback was presented on the screen for 2500 ms after each response. The word “Correct” appeared if the response was a hit or correct rejection, “Wrong” if it was a miss or false alarm, and “Hurry Up!” when the reaction time was longer than 1500 ms. The paradigm is illustrated in Figure 1.

The test session comprised three blocks of sixty trials each and participants were given a one-minute break between blocks. For each S1 duration (i.e. 500, 1500 and 3000 ms) in each block, there were ten trials where the S2 duration equaled the S1 duration, five where the S2 duration was 50% of the S1 duration (i.e., 250, 750 and 1500 ms) and five where the S2 was 50% longer than the S1 duration (i.e. 750, 2250 and 4500 ms). Given the duration between the fixation cross and the S1 onset depended on S1 duration, as described above, distracter trials were added for each condition to discourage participants from using the fixation cross to S1 delay as a cue to S1 duration. For six 500 ms S1 trials the fixation to S1 delay was 500 ms, for six 1500 ms S1 trials the fixation to S1 delay was 3000 ms, and for six 3000 ms S1 trials the fixation to S1 delay was 1500 ms. Therefore, there were 78 trials in total for each block. Participants completed ten training trials prior to the test session. Participants were instructed to begin timing with the signal onset for both S1 and S2 and that they would have to decide whether the S1 duration was the same or different from the subsequently presented S2 duration. They were also told to remember the duration of S1 during the inter-stimulus interval between the S1 and S2, and not to count.

**ERP Recording**

The electro-encephalographic (EEG) activity was recorded using Ag/AgCl electrodes, mounted in an elastic cap (Quikcap, Neuroscan), from 45 scalp sites (FP1, FP2, AF3, AF4, F7, F5, F3, F2, F4, F6, F8, FC5, FC3, FC1, FCZ, FC2, FC4, FC6, T7, T8, C5, C3, CZ, C4, C6, TP7, TP8, CP5, CP2, CP1, CP2, CP4, CP6, P7, P5, P3, P4, P6, P8, PO3, POZ, PO4, O1, OZ, and O2) of the extended 10-20 system. The electro-oculogram (EOG) was recorded from electrodes positioned at the outer canthus of each eye and just above and below the left eye. The reference electrode was placed on the nose and the left mastoid served as the ground. Resistance was kept at or below 5 kΩ for all electrodes. The EEG and EOG were recorded.
continuously from 0 to 70 Hz at a sampling rate of 256 Hz. EEG data were processed using the Matlab based EEGLAB package (Delorme & Makeig, 2004). The data were filtered offline with a 0.1 to 30 Hz bandpass filter, followed by visual inspection to remove atypical artifacts in the continuous EEG data (e.g. infrequent, sudden fluctuations in only one electrode, very large shifts and segments with sudden high frequency noise). Independent component analysis (ICA), a special class of blind source separation method that separates signal mixtures into statistically independent signals (Stone, 2004), was applied. Components representing eye movement artifacts were removed and the retained components were back-projected as the data for epoching. By separating the eye blink components, artifacts are removed while leaving components reflecting brain processes intact, thus retaining useful data that would be lost if entire trials containing eye blink artifacts were removed. Event-related potentials (ERPs) time-locked to the offset of the second S1 marker were computed at all recording sites during the 2-second S1-S2 delay, with the 100 ms immediately prior to the offset of S1 serving as the baseline. For each participant, only epochs corresponding to correct responses (i.e. hit or correct rejection) were included in the ERP condition average.

Data Analysis

Data from six participants were excluded from further analysis due to either low accuracy across all conditions, excessive EOG artifacts and drifts in the EEG, highly noisy data or a combination of these factors. Therefore, data from 19 participants were used in the final analysis. Moreover, the 500 ms condition was excluded from the analysis because the ERP baseline period (i.e., the 100 ms preceding the offset of the second S1 marker) was not comparable to that in the 1500 and 3000 ms conditions, especially at parietal electrode locations. This difference was likely due to the short interval (400 ms) between the S1 markers, such that the neural activity elicited by the first S1 marker failed to return to baseline before the second S1 marker. As the 100 ms period before the S1 offset marker served as the electrical baseline reference for the brain response during the S1-S2 delay, any brain activity differences between conditions during this reference period could lead to spurious ERP differences during the time window of interest (i.e., the S1-S2 delay). On average, 30 and 21 trials per participant entered the statistical analysis of the ERPs for the 1500 and 3000 ms conditions, respectively.

Behavioral accuracy rates in the 1500 and 3000 ms conditions were analyzed with a one-way repeated measures ANOVA. For the ERP data, the electrodes were organized into six regions of interest (ROIs) for statistical analysis. The left frontal region (LF) included AF3, F3, F5, FC1, FC3, FC5; the right frontal region (RF) included AF4, F4, F6, FC2, FC4, and FC6; the left central region (LC) included C3, C5, CP1, CP3, CP5; the right central region (RC) included C4, C6, CP2, CP4, CP6; the left parietal region (LP) included PO3, P3, P5, O1; and the right parietal region (RP) included PO4, P4, P6, O2. ERP voltages were averaged across all electrodes in each region to form one virtual electrode for each region at each time point. For statistical analysis, the 2000 ms time window was divided into four time windows of 500 ms each. Mean ERP amplitudes were subjected to a three-way repeated measures ANOVA with Condition (1500 and 3000 ms), ROI (LF, RF, LC, RC, LP, and RP), and Time Window (TW, 0 to 500 ms, 500 to 1000 ms, 1000 to 1500 ms, and 1500 to 2000 ms) as within subjects factors. Greenhouse-Geisser correction was used in all cases where there were two or more degrees of freedom in the numerator. In the following, we report main effect and interaction terms that include the factor Condition only.

Results

Behavioral Performance
The mean number of correct responses was 47 out of 60 (79%) and 32 out of 60 (54%) for the 1500 and 3000 ms conditions, respectively. A one-way repeated measures ANOVA indicated that accuracy rate was significantly higher in the 1500 ms condition, $F(1,18) = 72.4$, $p < .01$.

ERP results
As illustrated in Figures 2 and 3, the ERPs elicited during the S1-S2 delay following the 3000 ms S1 stimulus were more positive than those following the 1500 ms S1 stimulus, and this difference extended to the onset of S2 (2000 ms
time point). An omnibus F test showed a significant main effect of Condition: \( F(1,18) = 8.868, p = .008 \), and a significant two-way interaction, Condition x ROI: \( F(2,31) = 3.783, p = .039 \), as well as a significant three-way Condition x TW x ROI interaction: \( F(4,67) = 2.975, p = .029 \).

To examine the interactions in greater detail, separate ANOVAs for each time window (i.e. two-way Condition x ROI for each TW) revealed either significant or marginally significant simple main effects of Condition at all time windows, TW1 (0 to 500 ms): \( F(1,18) = 7.663, p = .013 \); TW2 (500 to 1000 ms): \( F(1,18) = 4.494, p = .046 \); TW3 (1000 to 1500 ms): \( F(1,18) = 4.224, p = .055 \); and TW4 (1500 to 2000 ms): \( F(1,18) = 9.119, p = .007 \). In addition, there were significant two-way Condition x ROI interactions in TW2: \( F(2,31) = 5.297, p = .014 \); and TW3: \( F(2,31) = 6.667, p = .004 \). Post-hoc analyses of the second and third time windows revealed slow wave differences at frontal and central electrode locations that were of notable magnitude. In TW1, Left-Frontal: \( t(18) = 2.76, p = .013 \); Right Frontal: \( t(18) = 2.68, p = .015 \); Left Central: \( t(18) = 2.50, p = .022 \); and Right Central: \( t(18) = 2.20, p = .041 \). In TW3, Left Frontal: \( t(18) = 2.77, p = .013 \); Right Frontal: \( t(18) = 2.63, p = .017 \); Left Central: \( t(18) = 2.93, p = .009 \); and Right Central: \( t(18) = 2.069, p = .053 \). There were no significant differences between the two duration conditions at the posterior ROIs in either time window. In TW2, Left Parietal: \( t(18) = 1.18, p = .26 \); Right Parietal: \( t(18) = 1.03, p = .32 \). In TW3, Left Parietal: \( t(18) = .71, p = .49 \); Right Parietal: \( t(18) = .073, p = .94 \). The topographical distributions of the voltage difference between the 3000 and 1500 ms conditions for each of the four time windows are shown in Figure 4.

Figure 2 also shows that a negative component, the N100, occurred within 200 ms after the onset of the second S1 marker. However, a two-way Condition x ROI repeated measures ANOVA indicated there was no between condition voltage difference for the first 200 ms following onset of the second S1 marker, Condition: \( F(1,18) = 0.433, p = .52 \); Condition x ROI: \( F(2,42) = 0.607, p = .61 \).

Finally, Figure 2 suggests that a parietally focused positive component, the P300, occurred between 200 and 500 ms. A three-way Condition (1500 ms and 3000 ms) x ROI (six levels) x TW (three 100 ms time windows, namely 200 to 300 ms, 300 to 400 ms and 400 to 500 ms) repeated measures ANOVA revealed a significant main effect of Condition, \( F(1, 18) = 11.22, p = .004 \), but the Condition x ROI, \( F(1,26) = 2.98, p = .083 \), Condition x TW, \( F(2,31) = 2.71, p = .08 \), and Condition x ROI x TW, \( F(3,52) = 1.84, p = .154 \), interactions were non-significant.
Figure 3. Grand average ERPs, elicited during the S1-S2 delay interval, at one representative electrode for each of the regions of interest used in the statistical analysis. Note that the two conditions do not appear to differ during the first 200 ms after S1 offset, but show clear amplitude differences, with the 3000 ms S1 condition being more positive than the 1500 ms S1 condition, from about 200 ms until the end of the retention interval.

Figure 4. Scalp topographical plots showing the retention interval voltage differences between the 3000 ms and 1500 ms S1 conditions. The data were fitted to a 3D head model using EEGLAB.
Discussion

This study examined whether longer durations require more cognitive resources to maintain in memory than do shorter durations. During the 2000 ms delay between S1 and S2 presentation, the ERP slow wave that followed the longer S1 (3000 ms) was significantly more positive than that following the shorter S1 (1500 ms). Moreover, this difference was more prominent at frontal and central electrode sites between 500 and 1500 ms after the offset of S1. The spatial distribution of these slow waves was similar to that reported in other ERP/EEG studies of duration information processing (e.g., Monfort, et al., 2000; Monfort & Pouthas, 2003; Schubotz & Friederici, 1997) and the polarity and the magnitude of the amplitude difference were comparable to those reported by Monfort and Pouthas (2003) in their Gap trial modification of the standard S1-S2 paradigm.

It is important to note that the ERP waveforms obtained during the S1-S2 delay were non-phasic in nature and without distinct peaks for most of the delay period, the exceptions being N100 and parietal P300 components elicited by the second S1 marker. The P300 effect is discussed further below. By definition, the polarity of the sustained positivity obtained here indicates that it is not a CNV. Hence, the positive slow wave observed in this study is more consistent with a putative memory process than the temporal accumulation process usually associated with the CNV.

Moreover, given previous empirical support for the claim that slow wave magnitude tracks memory load (e.g. McEvoy et al., 1998), with larger amplitude slow waves reflecting greater memory load, the present results suggest that remembering a 3000 ms duration across a retention delay does indeed place a larger burden on the interval timing system than does remembering a 1500 ms duration. As such, the present results are consistent with the idea that a pacemaker-accumulator mechanism (e.g. Gibbon et al., 1984) underlies interval timing, with longer durations represented by a larger number of pacemaker pulses in the accumulator. The implication is that maintaining/representing a larger pulse count demands more cognitive resources in a similar manner to how maintaining multiple individual items in memory is also more demanding than representing a single item.

Allocation of attention has been closely tied to duration memory accuracy and is often proposed as an explanation of behavioral and neurophysiological effects in interval timing experiments. Within the pacemaker-accumulator framework, attention determines whether the switch is closed and pulses are transferred to the accumulator (e.g. Burle & Casini, 2001; Penney et al., 2005). Other empirical studies, in particular dual task paradigms (e.g. Brown, 1997; Coull et al., 2004; Rammsayer & Ulrich, 2005; Gontier et al., 2007), also highlighted the important interaction between allocation of attention and interval timing performance (see Brown, 2008 for review). In particular, non-temporal tasks that tap executive functions interfere with timing and vice versa. In the current study, there were no interfering tasks and the participants were able to apply full attention to retention/rehearsal of the S1 duration during the retention interval. Although there may have been effects during the presentation of the S1 itself, with longer S1 durations being more demanding of attention than shorter S1 durations, we attempted to control for this by manipulating the fixation cross to S1 onset across conditions. Thus, it is unlikely that there were condition differences in the allocation of attention during the retention interval that can account for the results obtained here. Moreover, the presence of a larger P300 for the 3000 ms as compared to the 1500 ms results is unlikely to be the source of the between condition SW difference over frontal and central electrode sites. The P300 response difference was probably due to the longer delay between S1 markers but we note that the P300 effect over parietal electrodes appeared to resolve by about 400 ms (Figure 3), whereas the frontal central SW effect was much longer lasting. In addition, it is possible to functionally isolate the P300 from frontal SW effects (Fabiani, Gratton & Coles, 2000).

While pacemaker-accumulator models have been highly successful in explaining a wide range of interval-timing behaviors in both humans and other animals, there are competing models, including those that propose different mechanisms for different time ranges. For example, some researchers claim that timing
durations spanning less than hundreds of milliseconds relies on automatic motor timing, whereas timing of seconds range stimuli relies on cognitively controlled timing system (e.g. Lewis & Miall, 2003). In addition, pharmacological studies have shown that sub-second and seconds range timing performance can be affected differentially by the same drug (e.g. Rammayer, this issue), and computational models have demonstrated the feasibility of sub-seconds timing without the need of a general clock (e.g. Mauk & Buonomano, 2004). However, in a recent review of PET and fMRI studies of timekeeping mechanisms, Penney and Vaitilingam (2008) compared the neural substrates implicated in sub- and supra-second timing across various timing paradigms and concluded that the two time ranges may share a substantially similar neural network, if not precisely the same network.

Moreover, in the seconds to minutes range, the Striatal Beat Frequency (SBF) model posits that an interval is timed via the detection of coincidental firing of cortical neurons that oscillate at different rates (e.g., Matell & Meck, 2000; Matell & Meck, 2004). Specifically, oscillatory firing of cortical neurons is initially synchronized by the onset of a stimulus and a particular temporal interval can be uniquely identified by the pattern of synchronized firing present at that time-point. Hence, within this framework, the magnitude of the duration being represented should not impact allocation of resources to represent that duration because the same groups of neurons can be used to read out different durations that are coded in the firing pattern present at that instant. Therefore, the SBF model does not appear to predict differential cognitive resource demand for maintaining different length durations in memory across a retention interval. However, Meck et al. (2008), in a recent review of the behavioral and neurophysiological evidence for SBF model, noted that with respect to ERP measures of interval timing “further studies must translate these issues involving different time ranges and frequency bands with respect to the SBF model and other forms of temporal integration” (P. 148).

To conclude, by manipulating the magnitude of the remembered duration and minimizing other task demands, we observed a more positive slow wave in the 3000 ms condition as compared to the 1500 ms condition. Building on earlier SW work, this finding implies that more cognitive resources are required to maintain representations of longer durations in memory and demonstrates the value of using ERP measures initially explored in non-timing domains to address basic questions about the interval timing system (cf. Tse & Penney, 2006). The polarity and the magnitude of the difference were in agreement with previous studies on temporal memory and SW (Monfort & Pouthas, 2003). Although we compared ERP waveforms from correct trials only, we note that discrimination accuracy was better for the 1500 ms than the 3000 ms condition and this may have influenced the results obtained. Finally, although the present finding is theoretically consistent with pacemaker-accumulator models of interval timing, it is important to note that such models have received strong challenges in recent years and these preliminary duration memory results must be interpreted cautiously (e.g. Eagleman, 2008).

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