11-21-2019

Contingent Negative Variation: Sensitivity to Directed Attention

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CONTINGENT NEGATIVE VARIATION: SENSITIVITY TO DIRECTED ATTENTION

by

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A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

Major: Psychology

The University of Memphis

December 2019

Abstract

The exact nature of the contingent negative variation (CNV) event-related potential (ERP) remains unclear after decades of research. Although this ERP has long been associated with anticipation of motor responses, it remains present in the absence of physical action. Attention and arousal may better account for production of this ERP. In the current study, we examined the role directed attention may play in CNV production, while controlling for the expectancy of stimulus presentation based on the mean probability of stimulus duration. We hypothesized that if direction of attention, rather than probability of stimulus presentation, had the most pronounced effect, differences in slope and mean amplitude during different measurement windows would be seen, based on the length of different auditory stimuli. CNV slope was found to differ as a function of attention allocation. The potential role attention plays on CNV production as it relates to complex, time-based decision-making processes is discussed.

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Introduction

The contingent negative variation (CNV), first described by Walter, Cooper, Aldridge, McCallum, and Winter (1964), is characterized by a sustained, negative shift of scalp-recorded brain activity from the onset of a warning stimulus (S_1) until the presentation of a target stimulus (S_2), after which the negative potential ends. Walter and colleagues (1964) believed that the CNV was reflective of attentional priming due to the learned association between S_1 and S_2, in which anticipation is heightened and sustained until the target stimulus is terminated via a motor response (e.g., pressing a button). Although this appears to be generally true, researchers continue to debate what processes the CNV most reflects. Identification of this consistent, pronounced event-related potential (ERP) stimulated a surge of research during the 1960s-1980s (e.g., Hillyard, 1968; Loveless & Sanford, 1975; Nageishi & Shimokochi, 1983; Tecce, 1972), one that has continued to the present (e.g., Kononowicz & Penney, 2016; Wiener & Thompson, 2015).

Psychological Correlates

Although the CNV can be partially influenced by the physical properties of a stimulus, this response has been described mostly as an endogenous potential that is influenced by the context of a situation and the cognitive processes that take place within the individual (Donchin, Ritter, & McCallum, 1978; Picton, 1988). Various paradigms have been implemented for studying the CNV, such as presenting clicks and flashes (e.g., Walter et al., 1964), pure tones of varying frequency or length (e.g., Lukhanina, Karaban', Burenok, Mel'nik, & Berezetskaya, 2006; Nagai et al., 2004), and static and dynamic images (e.g., Duan, Wang, Fernández, Zhang, & Wu, 2016; Linssen et al., 2011). Paradigmatic approaches also differ in the method of stimulus presentation. Some use distinct and separate stimuli for S_1 and S_2 with varied durations between presentations (e.g., Walter et al., 1964; Nagai et al., 2004), while others present S_1 for an extended period of time with S_2 denoting an alteration or termination of S_1 (e.g., Duan et al., 2016; Linssen et al., 2011; Lukhanina et al., 2006). In the majority of studies, researchers have utilized a motor response task (i.e., participants press a button or lever when the target stimulus is presented). Thus, traditionally, the CNV has been most strongly associated with anticipation of a motor response. In other words, this ERP was thought to be a reflection of anticipating a physical movement, such as a button press in response to S_2.

However, one of the most comprehensive reviews on processes underlying the CNV, appearing less than a decade after the seminal work of Walter et al. (1964) was published, concluded that the prevailing theories of the time pertaining to CNV production that focused on anticipation, motor response, or motivation alone, were inadequate for capturing the full complexity of the CNV (Tecce, 1972). Teece's exhaustive review provided strong evidence that attention and arousal were the psychological processes most clearly linked to the CNV. While this may be the case, Hillyard (1974) later proposed the multiple CNV hypothesis, suggesting that different psychological processes may produce different types of CNV responses, which could then be represented by a composite of activity recorded from one area of electrodes. In line with these theories, distinctions have been made between early and late subcomponents of the CNV, wherein the former subcomponent is thought to be associated with automatic processing of the warning stimulus and the latter is more associated with motor response preparation (Siniatchkin & Gerber, 2011; Tecce, 1972; Walter et al., 1964).

Alongside earlier reviews (e.g., Tecce 1972), Mento, Tarantino, Sarlo, and Bisiacchi (2013) were more recently able to show that the CNV could be elicited even in the absence of an overt motor response. In their study, participants were presented both auditory and visual stimuli and given minimal instructions (simply watch a screen while their brain activity was recorded). Each trial consisted of a pair of stimuli, each lasting 500 ms: S_1 was a 500-Hz warning tone paired with a red cross. S_2 was a 1000-Hz tone paired with a yellow smiling face. The interval between S_1 offset and S_2 onset was either 1500 ms, 2500 ms, or 3000 ms. In order to induce the CNV absent a motor task while simultaneously exploring the role of temporal expectancies, the researchers implemented an oddball paradigm for the presentation of stimuli, with 70% of trials containing 1500 ms between S_1-S_2 pairs and 15% with 2500 or 3000 ms, respectively, between S_1-S_2 pairs. CNVs occurred in the absence of a button-press, and even in the absence of any conscious cognitive process, providing further evidence that the CNV is not merely related to motor response anticipation. Of equal importance, the researchers found that when the oddball pairs were presented, the CNV amplitudes tended to slope toward positivity, starting where S_2 would most frequently occur (the standard interval). The authors attributed this deflection of the CNV as reflecting implicit learning of the temporal rule (i.e., participants expected the stimulus to end at the most common time interval).

The study by Mento and colleagues (2013) is the only investigation we could locate in the past 5 years that effectively elicited the CNV using a "passive" paradigm; i.e., one where participants did not execute any motor actions, such as a button press, in response to the target stimuli. The attention hypothesis proposed by Tecce (1972) and the multiple CNV hypothesis by Hillyard (1974) help explain why passive paradigms, such as that used by Mento et al. (2013), are able to reliably elicit the CNV. While these accounts are highly plausible, complex, time-based decision making may also be involved. Although the role CNV plays in time-based processes continues to be debated (Kononowicz & Penney, 2016; Kononowicz & van Rijn, 2014), functional brain correlates suggest the CNV may very well be influenced by these processes.

Functional Brain Correlates

Although researchers generally agree about broad areas of the brain that are likely involved in CNV production, a consensus about the exact location where this ERP is generated or if multiple locations are involved has yet to be reached. The supplementary motor area (SMA) and anterior cingulate cortex (ACC) have been consistently associated with the CNV (Gómez, Marco, & Grau, 2003; Liu et al., 2013; Mento, Tarantino, Sarlo, & Bisiacchi, 2013; Nagai et al., 2004). Inconsistent findings among studies, alongside the general patchy, multiregional distribution of cortical activity related to the CNV, suggest that there may in fact be multiple generators and multiple types of CNV responses (Hamano et al., 1997), in line with Hillyard's multiple CNV hypothesis (1974).

Although the SMA has been theorized to be a common accumulator for temporal processing, or where information for subjective processing of time is stored and integrated, it is likely that deeper structures and a series of neural substrates are responsible for such processes (van Rijn, Kononowicz, Meck, Ng, & Penney, 2011). The SMA is part of a thalamo-cortico-striatal network theorized to be involved in temporal processing (Kotz & Schwartze, 2011; Macar & Vidal, 2004). Areas involved in this network have shown activation during fMRI studies of time estimation tasks (Pouthas et al., 2005) and forewarned reaction time tasks (Nagai et al., 2004), as well as tasks requiring greater attentional allocation to time (as opposed to color [Macar, Coull, & Vidal, 2006] or pitch [Liu et al., 2013]). One study utilizing both ERPs and fMRI found the CNV was associated with this network (Fan, 2007), providing some support for the CNV as a potential indicator of time estimation processes. However, it has been proposed that the CNV is not just a basic reflection of temporal accumulation (i.e., CNV amplitude is reflective of the subjective experience of time), but rather decision-making processes in relation to or governed by time processing (Kononowicz & Penney, 2016; Kononowicz & van Rijn, 2014).

In regard to attentional processes, applying low frequency repetitive transcranial magnetic stimulation (rTMS) to the right dorsolateral prefrontal cortex (rDLPFC) in order to inhibit neuronal activation produced a reduced CNV amplitude in comparison to sham rTMS in one study (Mannarelli et al., 2015). This effect was pronounced in the early CNV subcomponent, as opposed to the late CNV subcomponent that is associated with motor responses. The fact that inhibiting this area of the brain, which is associated with sustaining attention and maintaining alertness, resulted in a reduced CNV amplitude provides further evidence that this response is associated with attentional processes.

Current Study

The current study was designed to build on the study by Mento and colleagues (2013) and further explore the CNV as it relates to attention and time processing, while simultaneously minimizing the potential confounding role of prior probability of stimulus duration presentation. Although the CNV was sustained until the end of each stimulus in Mento et al. (2013), the slope of the CNV went from negative to positive during stimuli that continued beyond the standard stimulus duration. Even though this finding suggests that the CNV reflects automatic time expectancies, the effects could also be accounted for simply by expectancy created by the relative probability of each stimulus (i.e., frequent versus infrequent stimuli) being incorporated into the design. Prior probability of stimuli is known to influence CNV amplitudes (Scheibe, Schubert, Sommer, & Heekeren, 2009; Trillenberg, Verleger, Wascher, Wauschkuhn, & Wessel, 2000), such that there may be habituation based on the frequent probability of the standard interval between stimuli.

In the current study, we utilized directed attention in order to further evaluate CNV as an indicator of time expectancies, not just motor responses, while controlling for the confounding role of expectancies based on the relative probabilities of the stimuli. We reasoned that by manipulating stimuli wherein the probability of the presentation of one of three stimulus durations remained equal while differentially directing attention in different tasks, it would be possible to tease out whether the CNV is more sensitive to expectancy of stimulus presentation based on the mean probability of stimulus duration (henceforth referred to simply as "probability") or expectancy based on the target, at determined by the instructions (henceforth referred to as "attention"). Thus, the specific goal of the current study was to test how directed attention to stimuli of differing durations affected the CNV, as well as to test the general feasibility of a response-free auditory-only task in eliciting the CNV. If CNV amplitude is primarily sensitive to probability, it should peak similarly across conditions, regardless of which stimuli attention is directed toward (see Figure 1a). However, if attention plays a dominant role, a prediction derived from Tecce's (1972) theory linking attentional processes to CNV production, then varying attentional focus to either the shortest or longest of the three stimuli should alter CNV amplitude, with higher CNV amplitudes toward the target stimulus (see Figure 1b). Based on Konowicz and van Rijn (2014) and Mento and colleagues (2013), we predicted further that the slope of the CNV would continue to increase in negativity when attention was directed toward counting long stimuli versus short stimuli, specifically during the measurement window that captures the mean of all stimulus durations.

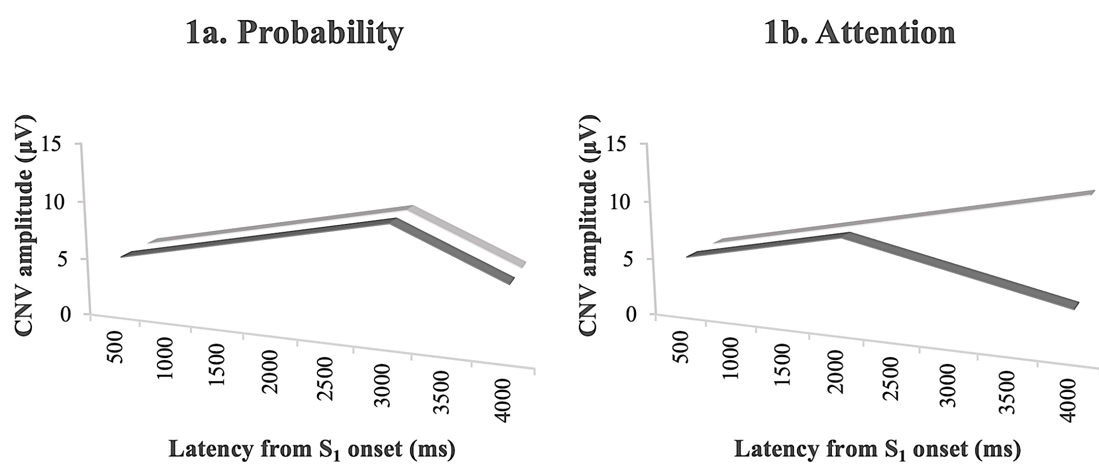

Figure 1. Visual depiction of competing hypotheses. If the CNV is particularly sensitive to probability (1a), we would expect amplitudes to be similar across conditions. However, if directing attention has a greater effect (1b), we would expect sustained negativity when participants are told to focus on long- (light line) versus short- (dark line) tone stimuli.

Method

Participants

Nineteen participants were recruited from a university participant pool (Sona) and received partial credit toward course requirements. Data from 4 participants were excluded due to technical failures (one EEG recording stopped abruptly, one had extremely high impedance values, and two sessions were interrupted by software pop-up windows) resulting in incomplete data. The remaining 15 participants were 18 to 48 years old (M = 25.93, SD = 10.29) with 12 to 23 years of education (M = 15.73, SD = 3.23), and included 11 male and 4 female participants. Reported ethnicities of participants were as follows: 9 White, 3 Black or African American, 1 Hispanic or Latino, 1 Middle Eastern, and 1 Asian. All reported normal hearing and all but three reported being right-handed. One participant reported loss of consciousness for 30 minutes or less 1.5 years prior to participating but reported that a follow-up examination with a neurologist revealed no residual problems.

Stimulus Presentation and Data Acquisition

Stimuli. Each stimulus contained a harmonically enriched 500-Hz predictor tone with harmonics at 1000 (-3 dB) and 1500 Hz (-6 dB) with a 100-ms, 1000-Hz target tone with harmonics at 2000 (-3 dB) and 3000 Hz (-6 dB) immediately following. Short-, medium-, and long-tone stimuli were 2 s, 3 s, and 4 s in duration, respectively. All tone durations included a 5-ms Guassian onset and offset. Each of the 3 stimuli were presented in randomized order with equal probability (i.e., P = .33) of presentation (40 each, totaling 120 per block). Time between stimulus presentation (ITIs) varied pseudorandomly from 900 to 1900 ms, in 100-ms increments. Tones were presented using SuperLab (version 5.0.5, Cedrus Corp.) at approximately 70 dB SPL through over-ear headphones, and the onset of each stimulus was marked in the EEG data file using a StimTracker (ST-100, Cedrus Corp.). In an effort to reduce eye movement artifacts during recording, participants were instructed to fixate on a 1-cm white cross on a computer screen in front of them while attending to the tones (as recommended by Weerts & Lang, 1973).

Data recording. Gold cup electrodes were used to continuously record the EEG. A single electrode was placed at Cz, where CNV amplitude is typically largest, referenced to an electrode placed on the right mastoid. A ground electrode was placed on the left mastoid. Data were acquired with a computer-based data acquisition system (MP36, Biopac Systems, Inc.) and Biopac Student Lab software (version 4.1.0). Data were sampled at 500 Hz and filtered online with a DC-100 Hz bandpass and a notch at 60 Hz. Although individual responses to the number of tones counted was not of specific interest, we reviewed responses so that relative accuracy could be analyzed to determine if participants were actually devoting sufficient attention to the tone-counting task as requested.

Design and Procedure

All procedures were approved by the Institutional Review Board (see IRB Approval), with each participant providing written consent to participate. Participants were seated with their faces located approximately 61 cm from a 35.5-cm computer screen with the keyboard placed in front of them. Once the electrodes were attached (described in detail in "Data recording"), over-ear headphones were placed on the participant and study instructions were displayed on the computer screen. Participants then completed a brief training period designed to teach them to distinguish the difference between the three stimulus types. After the training was completed, participants were encouraged to ask any questions they had about their assigned tasks to help ensure correct performance during the experiment and, further, that we were measuring the correct construct.

Using a within-subjects design, each participant was exposed to two tasks in which attention was directed toward either the short-tone stimuli (termed “Count Short”) or long-tone stimuli (termed “Count Long”), with the order being counterbalanced to control for order effects. One-hundred twenty (120) trials occurred within each task (again with 40 presentations of each short-, medium-, and long-tone stimulus). After each task, participants were prompted on the computer to type in how many tones they counted. Participants were given the option of taking a brief break between tasks if desired.

Data Processing and Analyses

Trials for each type of stimulus (short-, medium-, and long-tone) within each task (Count Short and Count Long) were averaged using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) for each participant. Although participants were directed specifically to count the short- and long-tone stimuli in tasks, medium-tone stimuli were included in analyses for comparison. This is because the mean expectancy based on the relative probability of the stimulus durations would be 3 s, and we would expect there to be smaller differences among the three types of stimuli across conditions if the strength of the expectation based on the probability was greater than that of attention. Data were filtered offline with a DC-30 bandpass. Trials with activity in excess of ±120 microvolts were rejected before averaging. An average of 27 trials for the Count Short task (*SD* = 20) and 25 for the Count Long task (*SD* = 25) were rejected from the total 120 trials in each task. Each participants' mean amplitude and slope were calculated using Microsoft Excel (version 15.20) for each tone stimulus in separate measurement windows of interest (500-2000 ms, 2000-3000 ms, and 3000-4000 ms after stimulus onset).

Amplitudes and slopes were analyzed separately using 2 (Count Short vs. Count Long) x 3 (short- vs. medium- vs. long-tone stimuli) x 3 (500-2000 vs. 2000-3000 vs. 3000-4000 ms) repeated-measures ANOVAs. Mauchly's tests of sphericity were conducted on each effect. If a significant violation of sphericity ($\alpha = .05$) was found, a Greenhouse-Geisser (G-G) correction was applied. In those cases, G-G epsilon and the corrected *p*-value are reported. A criterion of $p \leq .05$ was used to determine statistical significance. Bonferroni post-hoc analyses were conducted as appropriate.

Because of our specific interest in the CNV slope during the measurement window that would contain the mean of all stimulus durations, we conducted a 2 (medium- vs. long-tone stimuli) x 2 (Count Short vs. Count Long) repeated-measures ANOVA on the CNV slope using only 3- and 4-s tone stimuli during the 2000 to 3000-ms measurement window. This analysis was conducted only with medium- and long-tone stimuli, as the CNV for the short-tone stimuli had ended by this time point and we were primarily interested in the slopes of the CNV among the 3- and 4-s tone stimuli. If attention had a strong effect, we would expect the slopes of these stimuli to differ between the Count Short and Count Long tasks – specifically, for slopes to become more positive during the Count Short task and more negative in the Count Long task (Figure

1b). In contrast, if probability was the dominant factor, the slopes should be similar in both conditions (Figure 1a).

Results

Separate ERP waveforms for each of the three types of stimuli during the Count Short and Count Long tasks, respectively, are displayed in Figure 2. Visually, the onset of each stimulus elicited a typical N1-P2 complex, followed by sustained negativity (i.e., CNV) for the duration of the initial tone. The brief, second tone elicited an N1, followed immediately by a large positive shift, overshooting the baseline potential.

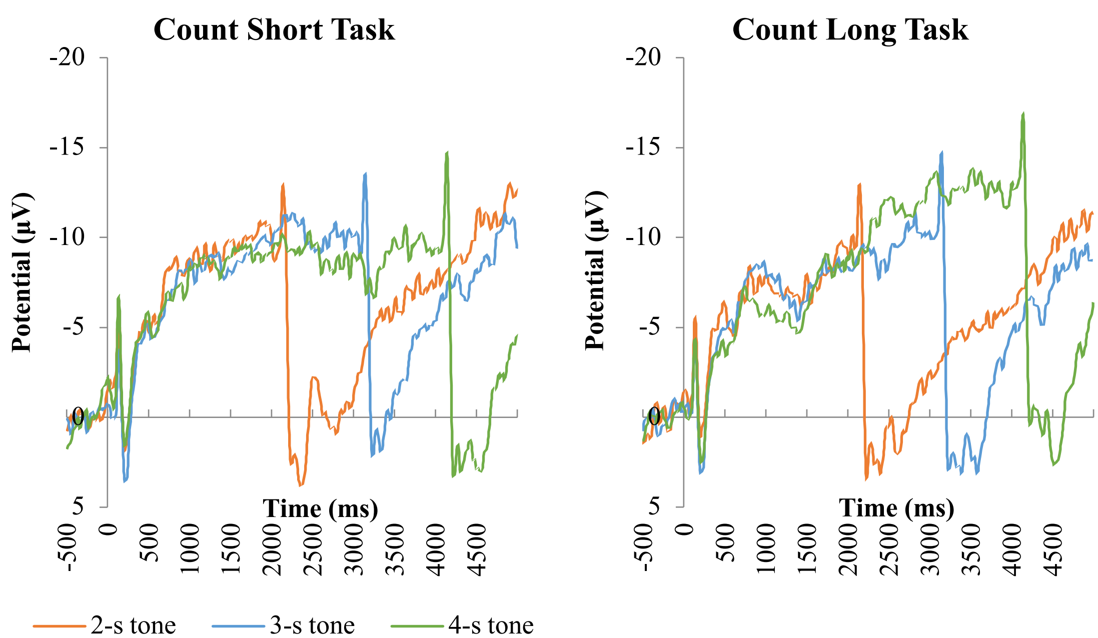

Figure 2. ERPs of short- (2-s), medium- (3-s), and long- (4-s) stimuli for the Count Short and Count Long tasks. Zero marks the onset of the tones.

At the end of each task, participants were asked how many tones of interest they counted (out of 40 possible) so we could determine the degree to which they were accurately directing their attention. These behavioral data were collected from a subset of participants (n = 10) for analyses, as behavioral data from 5 cases was missing due to technical issues. The number of short-tone stimuli counted during the task were perceived fairly accurately overall (M = 39.40, SD = 10.65), whereas the number of long-tone stimuli were often underestimated (M = 27.30, SD = 13.38).

The slope of the CNV was negative (i.e., decreasing in amplitude) across the first 2 s (i.e., the duration of the short-tone stimulus) in all conditions. The slopes then diverged between the attention conditions, becoming positive during the Count Short task for the medium- and long-tone stimuli, but remaining negative during the same stimuli in the Count Long task (see Figures 2 and 3).

Slopes

Mean CNV slopes separated by task can be found in Figure 3. Averaged across all measurement windows, slopes were more negative for long-tone (M = -0.001) than for short-tone stimuli (M = 0.0001; main effect of tone, $F(2, 28) = 7.48$, $p = .003$, $\eta_p^2 = .348$). Additionally, slopes differed significantly between all three measurement windows, with the first measurement window being the most negative (M = -0.002), the s being the most positive (M = 0.002), and the third falling in between (M = -0.0004; main effect of measurement window, $F(2, 28) = 12.24$, $p < .001$, $\eta_p^2 = .466$).

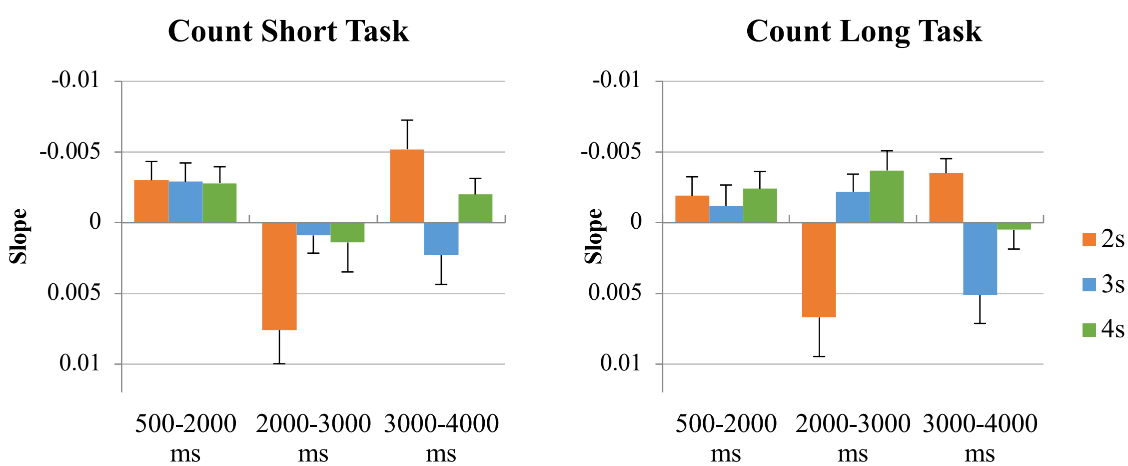

Figure 3. ERP slopes for the short-, medium-, and long-tone stimuli during each interval of interest for each task. Error bars represent standard error of the mean.

Across both tasks, slopes generally were negative. However, during the measurement window immediately following the CNV (i.e., 2000-3000 ms for the short-tone stimulus and 3000-4000 ms for the medium-tone stimulus), the slopes were relatively steep and positive.

A significant interaction was detected between tone and measurement window for slopes ($F(4, 56) = 19.59$, $p < .001$, $\eta_p^2 = .583$). During the 2000-3000 ms measurement window, the ERP slope for the short-tone stimuli was significantly more positive (M = .007) than both the medium- (M = -.001) and long-tone stimuli (M = -.001). During the 3000-4000 ms measurement window, the ERP slope differed significantly among all stimulus types. The ERP slope was negative (M = -.004) during the short-tone stimuli, positive (M = .004) during the medium-tone stimuli, and relatively flat (M = -.001) during the long-tone stimuli.

In addition, a significant interaction occurred between task and measurement window ($F(2, 28) = 5.44$, $p = .010$, $\eta_p^2 = .280$). During the Count Short task, CNV slope during the 2000-3000 ms measurement window was significantly more positive (M = .003) than during either the 500-2000 ms (M = -.003) or 3000-4000 ms windows (M = -.002). No significant differences were found between measurement windows during the Count Long task.

Mean Amplitudes

Mean amplitudes for each stimulus type and measurement window can be found in Figure 4, with a separate window provided for each task. Averaging across measurement windows, the mean amplitude increased with stimulus duration. Thus, across the entire 3500-ms period, the mean amplitude was significantly more negative for the long-tone (M = -9.36) than for the short-tone stimuli (M = -4.89; main effect of tone, $F(2, 28) = 7.84$, $p = .002$, $\eta_p^2 = .359$). During the CNV, no significant differences were found with respect to mean amplitude. Once the CNV ended, however, the mean amplitude decreased significantly. This produced a significant interaction between tone and measurement window ($F(4, 56) = 33.32$, $p < .001$, G-G $\varepsilon = .546$, $\eta_p^2 = .704$). In the 2000-3000 ms measurement window, the mean amplitude for the short-tone stimuli was significantly more positive (M = -1.52) than both the medium- (M = -9.83) and long-tone stimuli (M = -10.02; see Figure 4). During the 3000-4000 ms measurement window, the mean amplitude for the long-tone stimuli was significantly more negative (M = -10.86) than the short- (M = -5.15) and medium-tone stimuli (M = -2.79). Overall, CNV amplitudes were most negative (i.e., peaked) during the measurement window in which they ended.

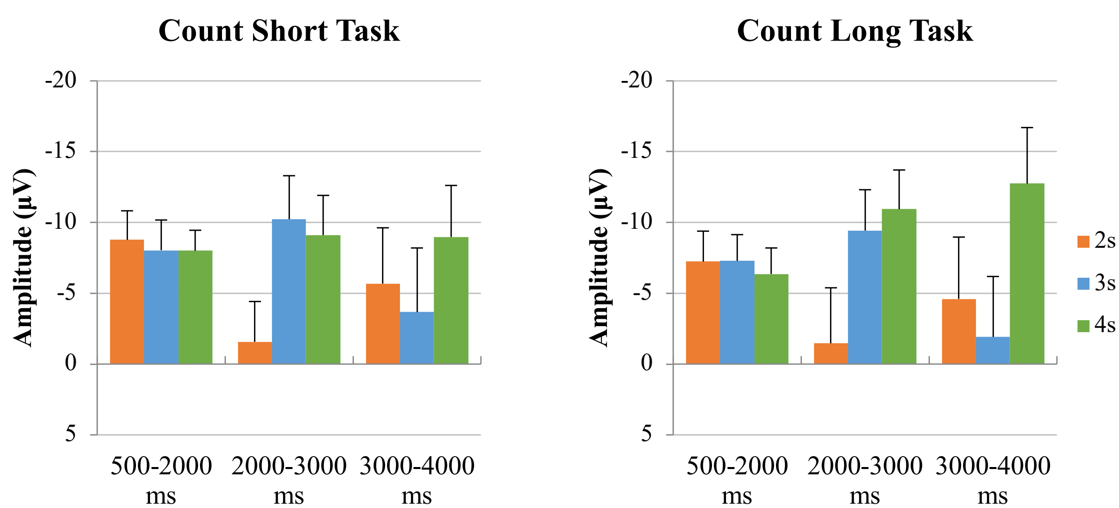

Figure 4. Mean ERP amplitudes for the short-, medium-, and long-tone stimuli during each measurement window for each task. Error bars represent standard error of the mean.

Planned Test of Hypothesis

As mentioned above, visual inspection of the CNV slopes during the 2000-3000 ms measurement window for the medium- and long-tone stimuli revealed a negative slope during the Count Long task and a positive slope during the Count Short task (see Figure 5). Across both stimulus types, this difference was statistically significant ($F(1, 14) = 7.13$, $p = .018$, $\eta_p^2 = .337$). The slope was significantly more negative during the Count Long task ($M = -.003$) than during the Count Short task ($M = .001$) in this particular interval. Neither a significant main effect of tone ($F(1, 14) = .22$, $p = .650$, $\eta_p^2 = .015$), nor an interaction between task and tone ($F(1, 14) = 1.42$, $p = .253$, $\eta_p^2 = .092$), were found.

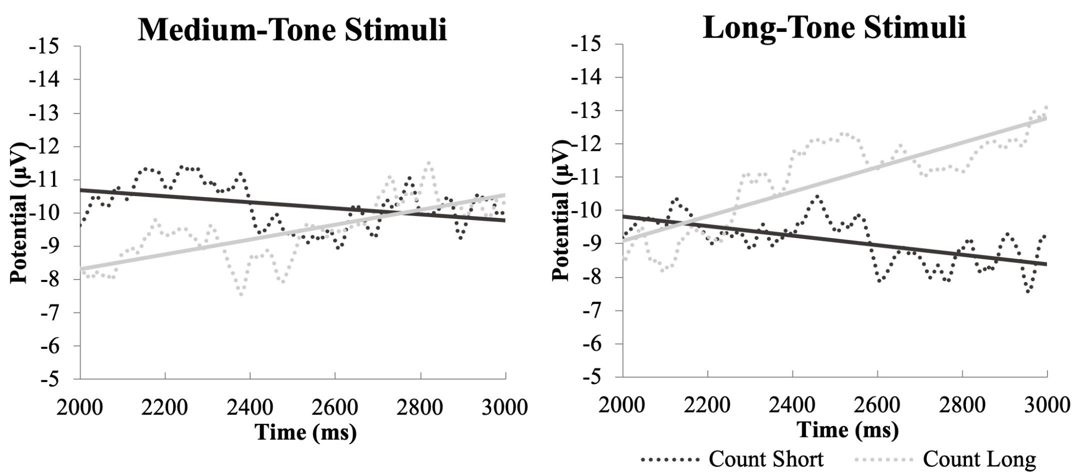

Figure 5. Dotted lines represent ERPs during the 2000-3000 ms interval for the Count Short and Count Long tasks, separated by medium- and long-tone stimuli. Solid lines represent the linear slope.

Discussion

The psychological processes driving the CNV remain somewhat enigmatic. The goal of the current study was to clarify one piece of the puzzle – that being further verification of the role attention plays in its production. By designing our study to pit expectancies induced by probability and directed attention in competition with one another, we were able to show directed attention had a greater influence on CNV production than the expectation based on the mean probability of stimulus presentation, as hypothesized. Moreover, as in Mento et al. (2013), CNVs were reliably produced using a passive paradigm (i.e., no overt response), showing feasibility and effectiveness of a response-free auditory-only task.

The mean duration of tones fell within the 2000-3000 ms measurement window in the current study. Drawing upon the findings of Mento et al. (2013), if probability was the dominant factor contributing to CNV production, then the slope should be negative during this middle measurement window in all conditions, becoming positive only after the 3-s point (refer back to Figure 1). The fact that slopes diverged in the different attention conditions during the 2000-3000 ms measurement window indicates that the attentional manipulation took priority over expectation based on probability of stimulus duration. This finding supports our hypothesis that attention is a greater contributing factor to the CNV than probability. Liu et al. (2013) similarly showed the CNV could be a reliable indicator of attention modulation across five alternative attention conditions in which CNV amplitudes developed as a function of attention allocated to stimulus timing. These results are also in line with Tecce's (1972) theory proposing that attention is a strong psychological component of CNV production.

The pivotal role of the attentional component comports with newer theories of the CNV being a reflection of complex time-based decision-making (Kononowicz & Penney, 2016; van Rijn, Kononowicz, Meck, Ng, & Penney, 2011). The reversal of slope that occurred at 2 s during the medium- and long-tone stimuli when individuals were instructed to pay attention to short-tone stimuli is similar to results from Macar and Vidal (2003) and Kononowicz & van Rijn (2014), where individuals were tasked with discriminating between stimuli of varying lengths. However, in these two studies, there was a large break, or deflection, when stimuli durations were longer than the standard interval (or target on which participants were basing judgments). In the current study, we see a similar pattern when participants were asked to attend to short stimuli, in which the slope of the CNV to stimuli that were longer than targets (i.e., short-tone stimuli) became more positive at the 2-s mark. This response, however, is not as pronounced, which may be due to the difference in the type of task used in the current study (i.e., internally keeping track of number of tones of a certain length across an entire block versus judging the length between stimuli pairs on individual trials).

Despite these differences, the deflection that we see may be reflective of individuals making a judgement that those tones were sufficiently dissimilar to short-tone stimuli, and thus not warranting further attention. Our study utilized a perceptual timing task, in which individuals were required, in essence, to remember and estimate timing of target tones in order to count how many times different types of tones occurred. We speculate that this process involves some sort of temporal decision-making influenced by where attention needs to be directed (e.g., deciding if a tone was short rather than medium or long), which is somewhat similar to Macar and Vidal (2003) and Kononowicz and van Rijn (2014), where participants were required to make judgements about stimuli based on time estimation.

Some results of our study are straightforward and would be expected in the results of any CNV study. For example, ERPs peaked during periods in which stimuli ended (N1 response to S_2), as is typical for the CNV. Additionally, the longer the tone duration, the more sustained the CNV. Finally, after the tone terminated, a large decrease in amplitude (increased positivity) occurred. These are all evidence that we were accurately measuring the CNV.

The current study is not without limitations. Of note, the number of long-tone stimuli was generally underestimated by participants, which may be due to difficulty distinguishing between medium- and long-tone stimuli or difficulty sustaining attention to longer stimuli. Although the large effect sizes obtained in the current study offset concerns about statistical power, replication with larger samples seems prudent for concerns about generalizability of these findings. Outcomes in future investigations may be enhanced if researchers take these results into consideration when designing studies, noting that directed attention does have an effect on CNV production. Future studies might profit as well by incorporating multiple checks of attention or further differentiating stimuli in order to document more fully the extent to which participants are truly attending to the stimuli of interest.

In summary, our findings suggest the CNV is influenced by the salient expectation related to temporal processing of sustained stimuli or stimulus pairs with a predictable relationship. Whether this occurs in response to images, as in Mento et al. (2013), or to sustained tones as in the current study, findings of an increased CNV amplitude may indicate that greater attention is being directed toward that stimulus. Our results, along with previous studies (Macar & Vidal, 2003; Mento et al., 2013; Kononowicz & van Rijn, 2014), show that the slope of the CNV is altered after the salient expectation of the stimulus duration has been met. In the case of Mento et al.

(2013), that consisted of the duration of the most probable stimulus, whereas in our study the duration of the tone was salient to the attention task. Thus, our results contribute to the understanding of the role that attention and task-relevance may play in temporal-based decision-making processes that the CNV reflects.

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IRB Approval

Date: 7-10-2017

IRB #: PRO-FY2017-515
Title: Investigating various measure of brain wave activity for developing neurofeedback approaches
Creation Date: 4-13-2017
End Date: 7-7-2018
Status: Approved
Principal Investigator: Lauren Dahlke
Review Board: University of Memphis Full Board
Sponsor:

Study History

Submission Type	Initial	**Review Type**	Expedited	**Decision**	Approved

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