The Dynamics of Infant Attention

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Abstract

Attention allocation and visual foraging are adaptively important behaviors in providing information about the world for effective goal-directed behavior and survival. Timely re-direction of gaze facilitates integration of information and provides exposure to new information, which is crucial during development. Steady-State Visual Evoked Potentials (SSVEPs) elicited in the extrastriate cortex by flickering stimuli can sensitively measure attentional switching. This study aimed to investigate the dynamics of attention in 3-month-old infants using SSVEPs by looking at how an attention-getting sound stimulus altered the spatial allocation of attention towards three flickering rubber ducks. For both the gaze fixated duck and non-fixated ducks, there was a significant decrease in relative amplitude of SSVEPs after a sound event was administered compared to a control event. This indicates that the sound stimulus served to globally decrease attention to all three ducks. Our results suggest that using SSVEPs can tell us new information about the dynamics of infant attention that could not be assessed using gaze alone, such as the intensity and direction of attention.

The Dynamics of Infant Attention

Attention allocation and visual foraging are adaptively important behaviors in providing information about the world for effective goal-directed behavior and survival (Robertson et al., 2004). Infants are active lookers, and shifting eye gaze is their main way of attending to stimuli in the environment, observing and processing important information about their external world (Posner, Rothbart, Farah, & Bruer, 2001). Although mechanisms of visual attention and processing change as one ages, research suggests that this behavior during infancy is important in sculpting the eventual adult brain, suggesting that infant attentional patterns could have effects seen later in life (Johnson, 2001).

Spatial attention is a combination of bottom-up and top-down processing (Corbetta, Patel, & Shulman, 2008). Peripheral, attention-grabbing stimuli orient attention in a bottom-up fashion by manipulating what an infant attends to. However, focus caused by voluntary attention and expectations is a top-down mode of processing (Corbetta, Patel, & Shulman, 2008). Colombo (2001) described that spatial orienting of attention is composed of the engagement of visual attention at a particular stimulus, the disengagement of visual attention from a stimulus, and the shifting of visual attention between stimuli. Spatial attention can also be either covert or overt. In covert orienting, the attentional shift occurs without a gaze shift, while overt orienting involves gaze shifting. An infant's ability to allocate his/her attention is important, as spatial attention enhances perception of items, integrates object features, reduces environmental

uncertainty, and helps incorporate information into short-term memory (Vecera & Rizzo, 2003).

Current research shows that stimuli in different sensory modalities can interact to orient spatial attention (Macaluso 2009). Richards (1998) has shown that during early infancy (infants 8, 14, 20 and 26 weeks-old), attention might be selectively modal. In his experiment, stimuli presented to elicit blinking were more effective when the blink-eliciting stimulus and the attended stimulus were in the same modality; infants showed an enhanced blink reflex to a sound stimulus if they were first attending to a sound stimulus as opposed to a visual stimulus. When the blink-eliciting stimulus modality differed from that of the attended stimulus (visual with auditory), the blink reflex was attenuated. Attention's effect on the blink reflex seen in this study suggests that infants show selective attention toward matched modalities. Ruff, Capozzoli, and Saltarelli (1996) have also looked at how a sound stimulus affects attention to visual stimuli. They found that 10 month old infants with a high level of attention toward a visual stimulus were less likely to turn their attention away from that stimulus than infants casually attending to a visual stimulus when presented with an auditory distracter stimulus. Their study also found that infants faced with a distracter auditory stimulus were more likely to maintain a high level of attention toward the current visual stimulus than infants who did not receive an auditory distraction. These results suggest that infants with a high level of attention to a stimulus are able to maintain this attention in the presence of extraneous stimuli.

In order to properly respond to the environment, infants must be able to shift the direction of their attention at appropriate times, making the dynamics of attention extremely important. Related to attentional dynamics is the process of visual foraging, which requires repeated gaze shifts from one object to another in the presence of multiple stimuli in order to explore the environment. Timely re-direction of gaze facilitates integration of information and provides exposure to new information, which is crucial during development (Robertson, Bacher, & Huntington, 2001).

Robertson et al. (2004) began exploring the dynamics of visual foraging in infants by creating a stochastic dynamical model that mirrors infant attention. This model found that one-month old infants' looking behavior could be represented without accounting for cognition, meaning that infant looking behavior might be independent of cognitive processes very early in development. Although cognition can play a part during gazing, it seems to have a much smaller impact on visual foraging than other mechanisms (Robertson et al., 2004). The two factors found to have a significant influence on gaze switching were random fluctuations in processes that help regulate attention (noise) and stickiness in infant gaze (hysteresis) (Robertson et al., 2004). These factors could represent spontaneous infant body movement and the inability of infants to shift their eyes off of a current focal point even after attention has diminished, respectively, which are both characteristics of infant looking behavior that have been previously identified. The Robertson et al. (2004) study's findings suggest that spontaneous bursts of body

movement and gaze stickiness could be the key factors controlling the dynamics of infant attention.

The finding that cognition might be less important in directing gaze than other factors, in addition to knowledge that covert attention cannot be studied using gaze, makes the study of the mechanism of infant attentional switching important. Previous research has shown that behavioral methods alone are insufficient in measuring attentional switching (Müller et al., 1998). Specifically, gaze, which is often used as a measure of attention, can become uncoupled from attention, especially before a gaze shift occurs (Robertson & Wilbourn, 2009). The use of steady-state visual evoked potentials (SSVEPs) to measure the time course of attentional switching can help increase understanding of attention dynamics, even to stimuli where gaze is not focused.

Steady-State Visual Evoked Potentials (SSVEPs) are elicited in the extrastriate visual cortex by flickering stimuli and can sensitively measure attentional switching (Belmonte, 1998; Müller et al., 1998). Flickering stimuli create oscillations in EEG (SSVEPs) that can be measured in the posterior region of the scalp over the visual cortex (DiRusso et al, 2007). As shown in Figure 1, SSVEP oscillations occur at the frequency of the flickering stimulus and display increases in amplitude when attention is focused on the stimulus (Morgan et al., 1996; Müller et al., 1998). This effect of attention is specifically seen in the occipital, temporo-occipital, and parieto-occipital regions (Hillyard et al., 1997; Müller et. al., 1998).

Robertson and Wilbourn (2009) found that SSVEP amplitude and phase locking in 3-month-olds increased when a center stimulus was rotated briefly to manipulate attention. This finding suggested that the increase of attention was facilitated by the locking of brain activity to the stimulus flicker, providing a more detailed look of how dynamic attention works. This study demonstrated how SSVEPs could be used to gain more information about the intensity and direction of attention by showing that increased synchrony of neural activity to stimulus flicker reflects increased attention.

The present study investigated the dynamics of attention in infancy by looking at how an attention-getting sound stimulus altered the spatial allocation of attention. More specifically, the study looked to determine whether sound perturbation would result in a broad increase in attention, a narrowing of attention on a current focal point, or a global decrease in attention. In this experiment, a sound perturbation was played after gaze to a central blinking rubber duck had been established, and SSVEPs elicited from the central duck and two peripheral ducks on either side were analyzed to assess attention. One possibility was that a sound perturbation would increase attention in a broad way; that is, attention to the peripheral ducks would increase. This result could indicate that an attention-getting sound event has the effect of broadening sensitivity of attention not limited to the source of the sound. Another possible result was that attention to the current focus (the center duck) would increase, indicating that this manipulation of attention does not change attention allocation, but increases attention to the fixated

object. Finally, it was possible that the sound manipulation would result in a global decrease in attention towards all three ducks.

Methods

Participants

Data were collected from 11 (6 male) healthy, 3-month-old infants with no known motor or sensory problems. Infants were recruited by including infant study interest slips with new parent paperwork at the Cayuga Medical Center. Interested parents were contacted by phone or e-mail when their child was the appropriate age for the study to schedule an appointment. Median gestational age at birth was 39 postmenstrual weeks (37-41) and median birth weight was 3536 g (2278- 4224 g). Median postnatal age at the time of this study was 85 days (82-89). Sixteen infants did not provide usable data due to insufficient looking for at least one control and one sound event (8), fussiness (2), unusable EEG (1), or because control or sound events did not meet length restrictions put in place for analysis (5).

Materials and Apparatus

An infant bumbo seat was placed 64 cm from three yellow rubber ducks, which were mounted in front of a black cloth screen. Additional black cloth screens to the left and right minimized visual distractions. Each duck was illuminated from the inside with four light emitting diodes (LEDs; Radio Shack 276-320) that flickered to drive SSVEPs; the center duck flickered at 12 Hz, and the left and right ducks (20 deg of visual angle from the center duck) flickered at either 8 or 10 Hz. The flicker frequency of the side

ducks was alternated based on even or odd date of participation. The LEDs on the left

and right sides of each duck body were always on; the LEDS in the center of the body

and head of each duck cycled between on and off at either 8 or 10 Hz (side ducks) or 12

Hz (center duck) with a duty cycle of 0.50. The luminance difference between the on and

off states was 35 cd/m^2 for the center duck and 58 cd/m^2 for the left and right ducks. The

LEDs allowed corneal reflections to be seen and recorded with a video camera behind a

hole in the black curtain directly above the center duck.

Attention was manipulated (sound events) by playing 2 seconds of infant-directed

speech or music either 1 or 3 seconds after the observer recorded infant looking at the

center duck. In control events, no sound played after looking at the center duck. Control

and sound events were chosen at random by the data acquisition program, which was

programmed to deliver an event after a center look was recorded by a research assistant

(see Procedure). The sounds included four infant-directed speech passages and three

musical noises which were equated for length, onset and offset time, and amplitude.

These sounds had been used successfully in previous infant studies in the Robertson Lab.

Procedure

The studies were scheduled at a time when parents indicated the infant would be

most alert. Once the infant was deemed to be alert and calm, he/she was placed in the

bumbo seat. The infant was outfitted with the EEG cap, made of cloth, containing

electrodes (Compumedics Ag/Ag/Cl sintered Quik-Cap electrodes) and conductive gel

(Electro-Gel, Electro-Cap International) and held on by an elastic tubular gauze headband

(Surgilast 5.5). EEG signals were amplified with a gain of 50,000 and band-pass filtered with 12 db/octave cut-offs at 1 and 100 Hz and a notch filter at 60 Hz (Grass Model 15), then digitized at 256 Hz with 12 bit resolution (National Instruments 6023E).

Infants were allowed to look freely at the three rubber ducks. A research assistant watched the corneal reflections of the ducks on a video monitor and held down a button that indicated to the data acquisition program (LabVIEW 8.5, National Instruments) when the infant looked on to the center duck. After signaling that the baby was looking at the center duck by pressing the button, either the sound event of infant-directed speech or music (1 or 3 seconds after the look onset) or the control event of no sound occurred. The sound was played from a speaker directly behind the center duck. The research assistant released the button when the infant looked away from the center duck. The data acquisition program recorded the timing and duration of all center looks. The accuracy of research assistant button operation was confirmed by offline coding of the video data to the nearest video frame at 32 frames a second. A trial was stopped if the infant became fussy or sleepy. For 2 infants, more than one attempt separated by short breaks was needed to obtain usable data.

Data Acquisition and Analysis

EEG was detected with 10 scalp electrodes over the extrastriate visual cortex (Figure 1 D). For each infant, all 5 electrodes on the left side and 4-5 (median = 5) electrodes on the right side provided usable data. Electrodes were excluded if the signal was flat or if there was a large amount of movement or other artifact (amplitude was

greater than ± 50 uV for more than 5% of the trial), before or after an event. The SSVEP

amplitude, phase, and phase locking of SSVEPs driven by each duck (the center

"Fixated" duck where infant gaze was fixated and the left and right "Non-Fixated" ducks)

were extracted from the EEG with the Fast Fourier Transform implemented in LabVIEW

8.5 (National Instruments) during the 1s interval immediately before the start of and after

the end of each control and sound event. Infants provided 1 - 4 (median = 2) usable

control events and 1 - 4 (median = 1) usable sound events. A usable event was one that

was administered after the infant's gaze was focused on the center duck. Gaze had to be

on the center duck for at least 1 s before and after event onset.

SSVEP relative amplitude was measured for each duck by dividing the EEG

amplitude at the duck's flicker frequency (either 8, 10, or 12 Hz) by the average of the

amplitude at the adjacent frequencies (8 ± 1, 10 ± 1, 12 ± 1 Hz). SSVEP phase was

defined as the delay of SSVEP amplitude peak compared to flicker onset, measured as a

fraction of the flicker cycle. Phase locking between SSVEP and duck flicker was

calculated across the two 500 ms intervals before an event was administered and the two

500 ms intervals after an event was administered, yielding estimates between 0 (no phase

locking) and 1 (complete phase locking).

Results

An Event Type (Control, Sound) X Duck (Fixated, Non-fixated) X Time (Before

event administration, After event administration) Analysis of Variance with repeated

measures on all three factors was run on the relative amplitude, phase, and phase locking of SSVEPs.

Relative Amplitude

ANOVA revealed a significant main effect of Event Type on the relative amplitude of SSVEPs, F (1, 10) = 5.05, p = 0.048. The relative amplitude was higher during control events (M = 2.05 ± .16, mean ± SEM) than sound events (M = 1.73 ± .11). There was also a significant main effect of Duck on relative amplitude of SSVEPs, F (1, 10) = 8.63, p = 0.015. Relative amplitude was greater towards the center duck where gaze was fixated (M = 2.29 ± .24) than to the peripheral, non-fixated ducks (M = 1.49 ± .08). There was also a significant main effect of Time on relative amplitude of SSVEPs, F (1, 10) = 7.45, p = 0.021. Relative amplitude was higher in the Before event timeframe (M = 2.09 ± .16) than the After event timeframe (M = 1.69 ± .11).

There was a significant Event X Time interaction on relative amplitude of SSVEPs, F (1, 10) = 6.52, p = . 029 (Figure 2). While amplitude was practically identical before the control and sound events were administered (M = 2.08 ± .20, M = 2.02 ± .19), amplitude was significantly lower after sound events (M = 1.36 ± .10) than control events (2.10 ± .18) There were no other significant interactions affecting relative amplitude of SSVEPs.

Phase

There were no significant main effects of Event Type, Duck, or Time on phase of SSVEPs with respect to flicker. There were also no significant interactions which resulted in a change in phase of SSVEPs (Figure 3).

Phase Locking

Repeated Measure Analysis of Variance revealed no significant main effect of Event Type on phase locking of SSVEPs. There was a significant main effect of Duck on phase locking of SSVEPs, F (1, 10) = 20.36, p = .001. Phase locking was higher for the fixated duck than the non-fixated duck. There was also a significant main effect of time on phase locking of SSVEPs, F (1, 10) = 17.73, p = .002. Phase locking was higher before event administration than after event administration. There was a significant Duck X Time interaction on phase locking of SSVEPs, F (1,10) = 6.818, p = .026. Phase locking was lower for the non-fixated duck after an event than for the fixated duck (Figure 4).

<div align="center">

Discussion

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SSVEPs were used to measure changes in attention induced by a sound event. Attention was significantly higher towards the fixated duck than the non-fixated duck. When a sound event was delivered, attention towards both the fixated and non-fixated ducks significantly declined compared to when a control event was delivered. This indicates that the delivery of the sound stimulus served as a global distracter, decreasing

attention not only to the fixated duck stimulus but the other peripheral stimuli. There was also a decrease in phase locking after the sound event.

The decrease in attention toward all three ducks disconfirms the other possible hypotheses about the effect of sound on attention. The current findings dispute the hypothesis that the sound would broadly increase attention to stimuli in the environment. This result would have suggested that the sound stimulus served to expand the sensitivity of attention to make the infant more ready to respond to the multiple stimuli in his/her environment. These findings also provide no evidence for the hypothesis that an unexpected sound narrows attention to the currently fixated object, which would indicate that the sound acts not as a distracter but as a means to increase attention to the current focal point in the environment. This result would have suggested that the sound might facilitate neural processing of the currently attended stimulus. Furthermore, the current data do not show different effects of the sound stimuli on each of the three ducks. This suggests that sound stimuli have a global effect of decreasing attention, as opposed to serving to redistribute attention.

We expected to see a decrease in phase locking toward the fixated and non-fixated ducks that followed the pattern of amplitude decrease. This is because decreased synchrony between stimulus flicker and brain activity might be one effect of declining attention. Robertson & Wilbourn (2009) found that SSVEP amplitude increases might be due to stronger phase locking between stimulus flicker and brain activity. However, our results suggest that amplitude changes do not show a direct relationship to phase locking.

Phase locking in the sound condition for the non-fixated ducks showed a much more dramatic decrease than for the fixated ducks, even though the amplitude change for both the fixated and non-fixated ducks in the sound condition was very similar. However, this larger decrease in phase locking toward the non-fixated ducks was not statistically significant, and there was not a significant Event Type X Duck X Time interaction (Figure 4).

There are a few speculations we can make based on the results, although more research is definitely needed to understand these findings. One possibility is that the auditory stimulus caused a dissociation between phase and gain effects of attention in the extrastriate cortex. Another possible explanation is that phase can still be locked even while amplitude is decreasing. Yet another possible reason for this finding is that the rate at which phase becomes unsynchronized with the stimulus may correlate to how locked phase was at the start; because phase-locking for the non-fixated duck started off lower than phase-locking for the fixated duck, perhaps it becomes unlocked more quickly. It would be beneficial to look at the changes in phase locking a few additional seconds after the sound event to see if these changes tell us anything about the relationship between phase locking and amplitude. It is also important to keep in mind that the difference in phase locking between fixated and non-fixated ducks in the sound condition, while large, was not significant. Having a larger sample size and greater power may be able to give us a clearer picture of whether there is a true interaction going on.

Previous research has also suggested that when an infant is fixated on an object, a distracter needs to be more salient to gain the infant's attention; this is because competition is biased toward the fixated object so that an infant can learn and take in important information about that object (Tellinghuisen, Oakes, & Tjebkes, 1999). Based on this research, our results suggest that infant-directed speech and musical noises, which were used as distracters, are important for infants' goals at this stage of development and therefore take attention away from stimuli that do not have the same reward value, despite the fact that they are novel. While the distracters may not make 3-month-olds more attentive to their visual environment, they may unlock infants' attention so that they can respond to these reward-indicative sounds.

Study Strengths

The strength of this study is the use of SSVEPs to measure attention. The use of SSVEPs has been shown to give a more accurate measure of attention than eye gaze, which often becomes uncoupled with attention before gaze shifts. The ability of SSVEPs to measure covert attention allows us to analyze attention that cannot be identified through eye gaze. Furthermore, it gives us quantifiable information about the direction and intensity of attention, and comparisons of attentional levels to different stimuli presented simultaneously. SSVEPs are also more useful than other evoked-potential measurements because of the strong signal produced that can be extracted rapidly from EEG and because they can measure changes in attention continuously over time (Müller

1998). By using SSVEPs, this study was able to look at how infant attention decreases on a global level to stimuli where gaze was fixated and non-fixated.

Study Limitations

One weakness of this study is the small sample size. The number of subjects used in this study was limited by a number of factors. The first factor was the limited amount of time available to complete the study. Another factor was the need to remove infants from the subject pool for a variety of reasons, including infant fussiness, insufficient SSVEP data, and failure to fixate on a stimulus. The limited number of subjects resulted in limited power to detect a possible three-way interaction between Event Type, Duck, and Time. Robertson et al. (2010) found in a previous study that attention to the right and left non-fixated ducks fluctuated, suggesting that there is a re-distribution of attention; however, our limited power did not allow us to see if the Fixated, Left, or Right Duck interacted with Event and Time. The current study suggests that there is a global decrease of attention, but more subjects might allow us to see how and if attention is re-distributed.

Additionally, the variable timing of the delivery of the control and sound events was a study weakness. Ideally, each event onset would occur at the exact same interval of time after look onset. However, variability of online tracking of center looks resulted in variability in the time of event delivery. As a consequence, pre-event attention could be changing naturally in that time, making attention levels different at the moment of event onset.

Future Directions

It would be beneficial for future research to investigate how body movement is involved in attention allocation influenced by sound stimuli. Body movement has been shown to play an important role in an infant's response to stimuli. Current research builds off the concept of embodied attention, which stresses that body movement and visual attention are tightly coupled processes. Chiel & Beer (1997) stated that "adaptive behavior is the result of the continuous interaction between the nervous system, the body, and the environment, each of which have rich, complicated, highly structured dynamics." Previous experiments have shown that shifts of gaze are preceded by a burst of body movement in infants (Robertson, Bacher, & Huntington, 2001), suggesting that body movement helps unlock gaze in order to promote visual foraging. This unlocking of gaze could be both beneficial and detrimental - beneficial in distributing attention across the environment, yet detrimental if interrupting attention too early. Furthermore, infants' suppression or rebounding of movement after a gaze shift and re-focus has been found to correlate with later attentional problems (Friedman, Watamura, & Robertson, 2005). These researchers reported that individual variation in the dynamic balance of suppression and activation of body movements at the beginning of looks in 3-month-olds was related to attentional problems in later childhood. Seeing how infants with different movement suppressing and rebounding behaviors are affected by an attention-getting sound event could help develop a better understanding of attentional switching (Robertson & Johnson, 2009

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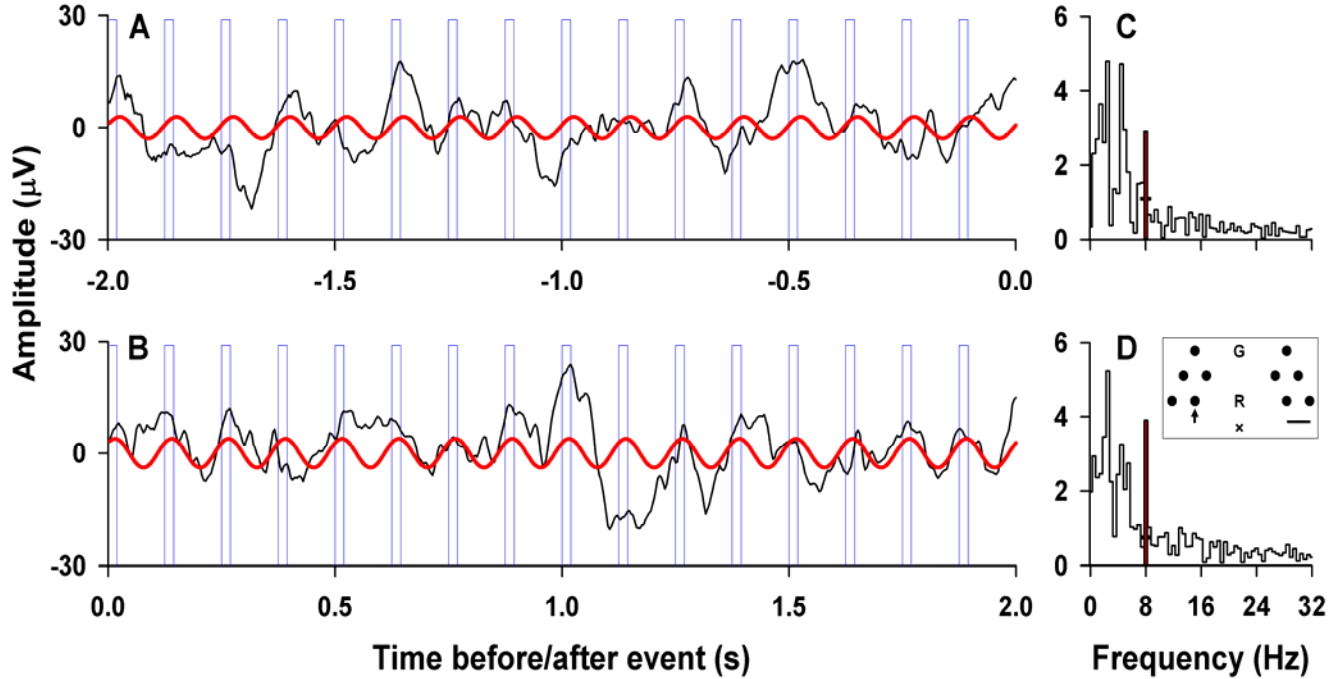
Figure 1

Figure 1: (A &B) An example of SSVEP (red line) extracted from EEG (black line) recorded by one temporo-occipital electrode by Fourier analysis of the EEG. Vertical bars show when LEDs of ducks were in the ON state.

(C&D) EEG amplitude at different frequencies, including the flicker frequency (8 Hz). D also shows the location of the electrodes (black circles) on the scalp, including the reference (R) and ground (G) electrodes. The inion is represented by the x; the scale bar is 2.5 cm.
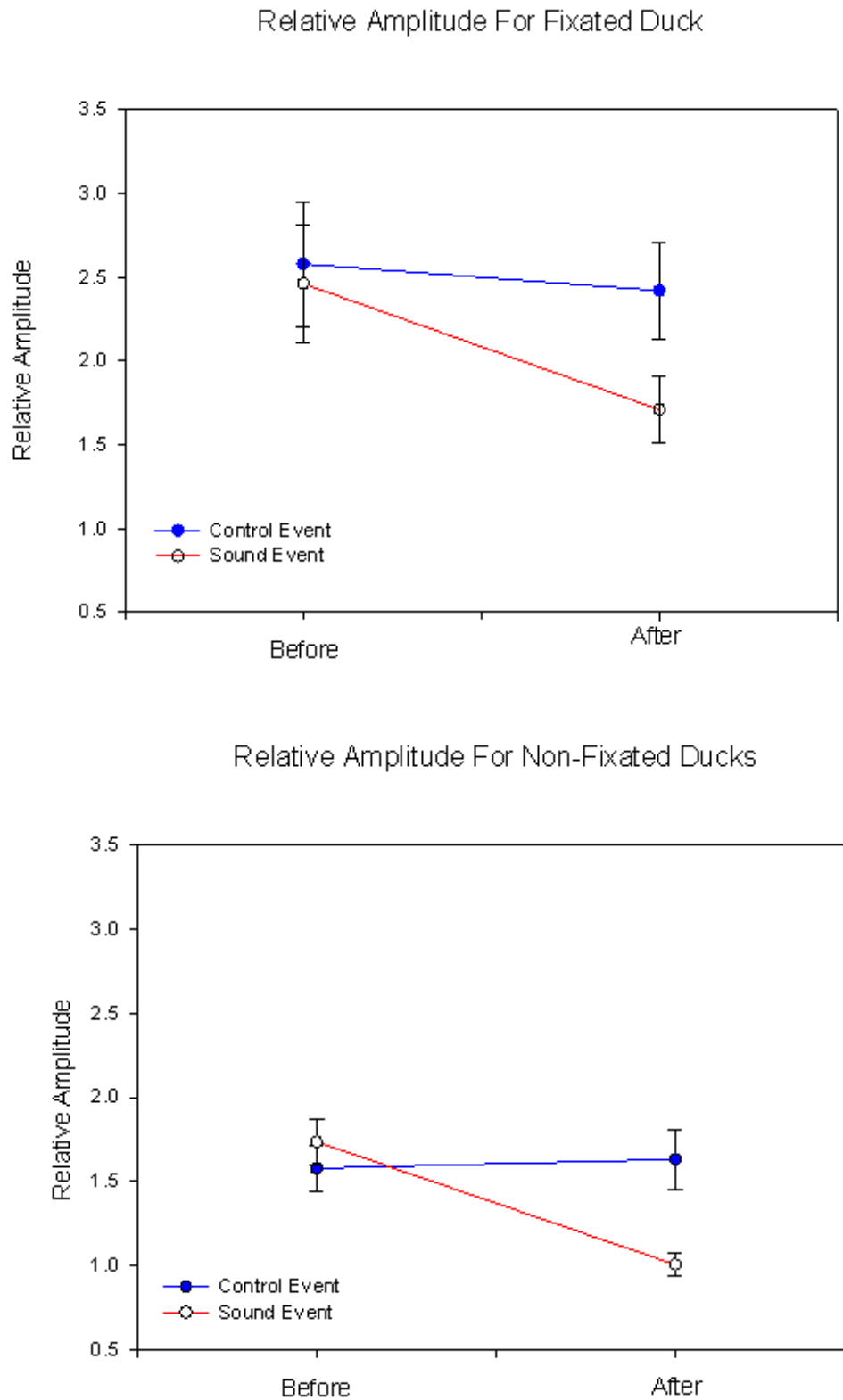
Figure 2

Figure 2: Relative amplitude (mean ± SEM) of SSVEPs driven by fixated and non-fixated ducks before and after sound and control events.
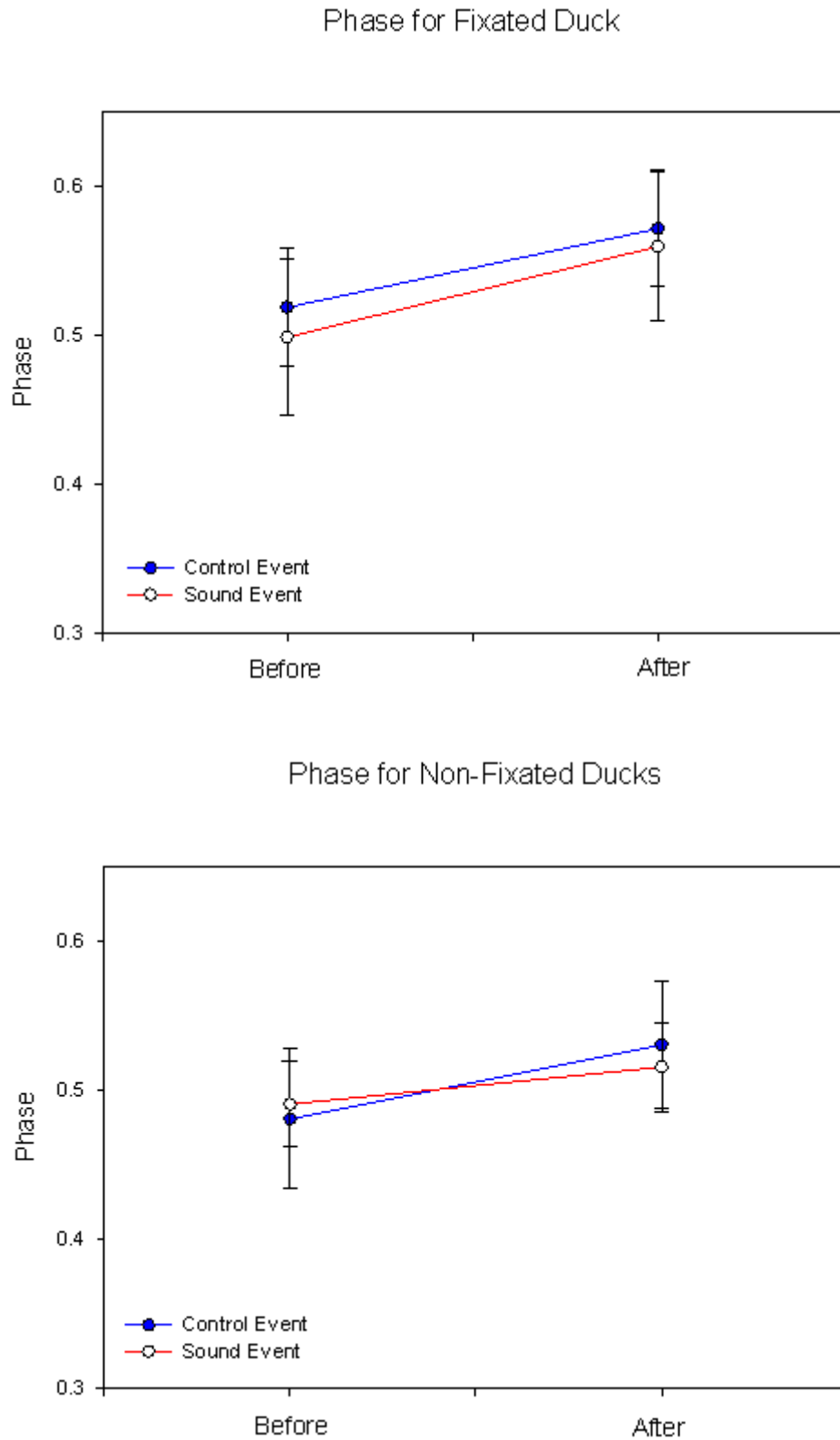
Figure 3

Figure 3: Phase (mean ± SEM) of SSVEPs driven by fixated and non-fixated ducks before and after sound and control events.
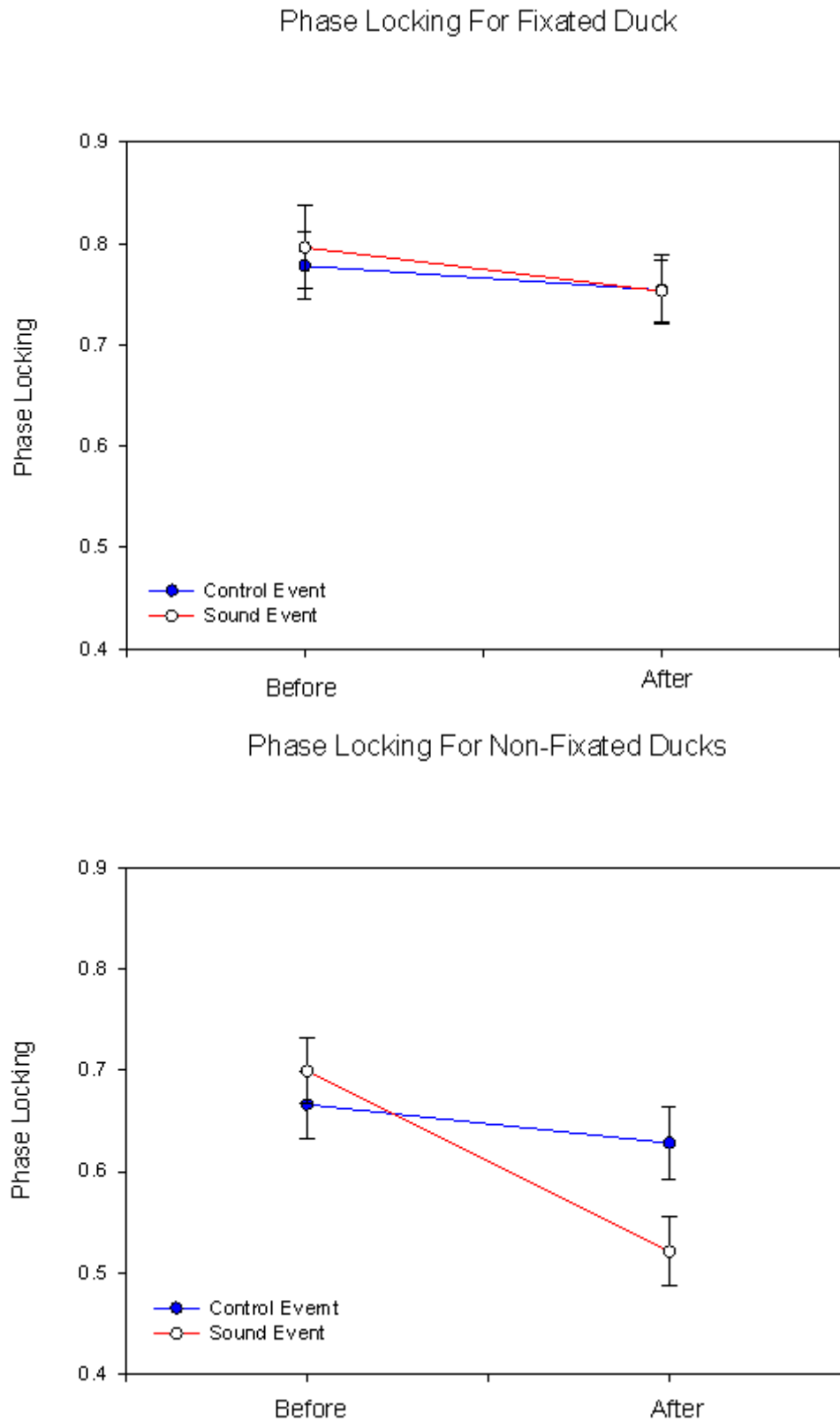
Figure 4

Phase Locking For Fixated Duck

Phase Locking For Non-Fixated Ducks

Figure 4: Phase locking (mean ± SEM) of SSVEPs driven by fixated and non-fixated ducks before and after sound and control events.