Cardiovascular Measures of Attention to Illusory and Nonillusory Visual Stimuli

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Abstract. This study was an extension of the Berntson, Cacioppo, and Fieldstone (1996) study that found that attending to visual illusions presented with text (usually a question directing attention to the illusory property) lengthened heart period via uncoupled vagal activation. Eighty participants were assigned to one of four groups that received either the original Berntson et al. illusions or a modification formed by the factorial combination of whether the illusion and its related text were present or absent. Participants also performed the same serial-subtraction mental-arithmetic task from Berntson et al. During the mental-arithmetic task heart period (HP) shortened, respiratory sinus arrhythmia (RSA) was reduced, and preejection period (PEP) shortened, which indicated a reciprocally coupled sympathetic activation and parasympathetic inhibition mode of cardiac control. Although idiographic analyses found this to be the most common control mode, all other modes were also obtained – especially the nonreciprocal modes of coactivation and coinhibition. During the visual task, PEP lengthened for all groups indicating uncoupled sympathetic inhibition while attending to the stimuli; however, HP differed depending upon the illusion factor. HP lengthened when illusions were absent, but unlike Berntson et al. it shortened when illusions were present. Idiographic analyses found that although most participants showed sympathetic inhibition, approximately equal numbers of participants showed parasympathetic activation and inhibition. Variation in response stereotypy may mask cardiac responses elicited by subtle cognitive phenomena such as the processing of visual illusions, especially in passive viewing tasks. We also suggest that individual differences in mental effort needed to integrate top-down and bottom-up perceptual processes, or personality variables such as the need for cognition, may contribute to response variability in the visual task.

Keywords: heart period, autonomic space, visual illusions, mental arithmetic

This study examines how processing illusory and nonillusory visual stimuli affects cardiovascular measures of attention. It partially replicates and extends the Berntson et al. (1996) study, which found that attending to visual illusions resulted in lengthened heart period (HP) elicited by uncoupled vagal activation. Their illusions were always presented with text directing the participant's attention to the illusory features of the stimulus. Thus, it was unclear whether their results were caused by the illusory nature of the figure, the text, or a combination of both factors. The current study attempted to separate the contributions of the illusory content of the figure and text to the cardiovascular responses obtained during the Berntson et al. illusion task.

Cardiovascular Reactivity in Attending to Visual Stimuli

Tasks involving cognitive effort or psychological stressors, such as mental arithmetic, have been consistently related to cardiac acceleration resulting from a reciprocal mode of sympathetic activation and vagal inhibition (Allen & Crowell, 1989; Allen, Obrist, Sherwood, & Crowell, 1987; Berntson et al, 1994a; Berntson et al., 1996; Grossman, Stemmler, & Meinhardt, 1990; Müller, Schandry, Montoya, & Gsellhofer, 1992). In contrast, tasks involving perceptual processing via visual attention have elicited cardiac deceleration (Berntson et al., 1996, Jennings, van der Molen, Somsen, & Brock, 1991; Lacey & Lacey, 1974; Libby, Lacey, & Lacey, 1973). Moreover, it is believed that increased vagal activity is predominant during attention (e.g., Somsen, Jennings, & van der Molen, 1988). Vagal predominance was corroborated in the Berntson et al. (1996) study of visual illusions. Berntson et al. found that participants exhibited uncoupled vagal activation while observing visual illusions. They suggested that if cognitive effort was minimized, sympathetic activation could be attenuated, and indeed sympathetic activation was not observed in their study.

However, visual illusions have not consistently produced cardiac slowing, as have other visual attention stimuli. For instance, Lenneman and Backs (2000) found that passively observing a continuously moving pattern of dots that formed geometric shapes produced little if any cardiac change. Further, Wood et al. (2000) reported slight increases in heart rate with vestibular-based tilt illusions. Such inconsistencies call for a better understanding of how illusory stimuli affect cardiac activity.

One possible reason for the mixed cardiac results to viewing illusions may be that illusions are a special subset of visual stimuli because the physical stimulus and the perception of that stimulus do not match. The extent to which illusions can be explained by data-driven (bottom-up) or conceptually-driven (top-down) processing is still controversial, but many theorists believe that both levels of explanation will be needed to understand most types of visual illusions (e.g., Gregory, 1997; Gunn, Warm, Dember, & Temple, 2000; Spillman & Dresp, 1995; Strüber & Stadler, 1999; Vecera & O'Reilly, 1998). Berntson et al. (1996) state that they chose visual illusions for their stimuli because ". . . illusions generally reflect immediate perceptual experiences, they do not demand appreciable cognitive processing and elaboration (p. 3)." However, processing some visual illusions may require more cognitive effort than others because of the greater need to integrate conflicting bottom-up and top-down processing while attending to the stimuli. Further, it may be that the cognitive processing of the text that Berntson et al. presented along with the illusions in their study changed the nature of the top-down/bottom-up integration of the illusion.

Current Study

In the current study, we attempted to replicate and extend Berntson and colleagues' (1996) finding that uncoupled vagal activation occurred while attending to visual illusions. As noted above, cardiac deceleration is indicative of an attention task requiring minimal cognitive effort. However, the failure to find a consistent pattern of cardiac deceleration while attending to illusions (i.e., Lenneman & Backs, 2000; Wood et al., 2000) suggests that attention to illusory stimuli may have multiple effects on cardiac activity, perhaps depending upon the need for bottom-up/top-down integration. Therefore, the current experiment was designed to replicate Berntson et al.'s illusion task and to extend the study in an attempt to isolate the perceptual and cognitive processing contributions to the cardiovascular responses to illusory stimuli.

The Berntson et al. task required participants to attend to a visual illusion that had text, usually a question, directing the participant to attend to the illusory aspect of the image. For instance with the Müller-Lyer illusion, the text would ask "Which line is longer?" They suggest that the text prompt, effectively directing the attention of the participant to the relevant features of the stimulus, may reduce the cognitive effort of processing the illusion. However, what effect the text had in their study is not clear as they did not have a condition where participants saw the illusions without the accompanying text.

It was also of interest to know whether the uncoupled vagal activation was specific to the illusions. That is, would the same pattern of results be obtained using similar but nonillusory stimuli? If there is considerable integration between top-down and bottom-up processing while perceiving and attending to an illusion, how would the processing of a similar nonillusory stimulus affect cardiac activity? For instance, would the magnitude of the cardiac response be attenuated for nonillusory stimuli because they require less attention or were less interesting?

Hence, we used a factorial design to parse the effects of attending to illusions with text-based prompts. Traditionally, tasks involving visual attention have resulted in cardiac deceleration (Jennings et al., 1991; Libby et al., 1973). Because the amount of cardiac deceleration increases as the images become more interesting (Libby et al., 1973), we hypothesized that there would be differences in cardiac activity between illusory and nonillusory figures. Further, if the text serves as a prompt to engage and direct the participant's attention to the illusory context, it may (1) make the stimuli more interesting, and (2) minimize cognitive effort associated with bottom-up/top-down integration, both of which may enhance cardiac deceleration. If so, those participants receiving the illusion and text should have greater cardiac deceleration than those participants who did not receive the illusion or the text.

We expected to replicate Berntson et al.'s (1996) finding of cardiac deceleration caused by uncoupled vagal activation for the illusory figures with text. Although we expected cardiac deceleration to the nonillusory figures and the illusions without text, we had no *a priori* hypotheses about the autonomic mode of control that would underlie these responses. Therefore, we performed both group-level (nomothetic) and individual participant-level (idiographic) analyses to clarify the mode of control and its consistency in these conditions.

Finally, we employed the same mental-arithmetic task used by Berntson et al. (1996) to serve as a comparison task to our visual tasks. The mental-arithmetic task should result in a pattern of cardiac acceleration produced by reciprocally coupled sympathetic activation and vagal inhibition.

Bivariate Model of Autonomic Control

The traditional view of autonomic control of target organs was that the parasympathetic and sympathetic branches of the autonomic nervous system (ANS) generally acted in a reciprocal fashion. A bivariate model of autonomic determinism has been proposed by Berntson, Cacioppo, and Quigley (1991, 1993) and Berntson et al. (1994b), which expanded upon and subsumed this traditional view. The bivariate model of autonomic determinism showed that there could be a functional independence between the two ANS branches, and that the two branches could act in other than the assumed reciprocal mode. Functional independence of the sympathetic and parasympathetic (vagal) activation of the heart, for example, results in three primary modes of autonomic control: Reciprocal, nonreciprocal, and uncoupled. A reciprocal mode of control encompasses the oft-noted patterns of ANS activity where sympathetic inhibition accompanies vagal activation, or sympathetic activation accompanies vagal inhibition. In addition, however, nonreciprocal modes occur when there is either a coactivation or a coinhibition of both sympathetic and vagal activity and uncoupled modes of control occur when there is activation or inhibition of either sympathetic or vagal activity, with no change in activity in the other branch. So, changes in chronotropic cardiac response are determined by the net change in activity of both ANS branches.

To determine the mode of autonomic control for HP, it is imperative to have measures that isolate sympathetic and vagal activity. Pharmacological blockades have been used to infer the relative contribution of each autonomic branch to different parameters of cardiovascular function. Specifically, preejection period (PEP) and respiratory sinus arrhythmia (RSA) were determined to be relatively good estimates of sympathetic and vagal activation, respectively (e.g., Berntson et al., 1994a; Cacioppo et al., 1994; Grossman et al., 1990; Stemmler, 1993). These measures provide good estimates under well-defined experimental conditions and have been shown to provide reasonable estimates of activity in the two branches in the tasks used here.

Method

Participants and Design

Eighty college students (40 female), ages 18–26 years, with a median age of 19 years, received extra credit or five dollars for their participation. A factorial combination of illusion (present or absent) and text (present or absent) was used to create the four groups, where 10 males and 10 females were randomly assigned to each of the conditions. The group that received both the visual illusion and the corresponding text replicated Bernston et al.'s (1996) illusion task, whereas the illusion present/text absent, illusion absent/text present, and illusion absent/text absent groups served to extend their study.

Apparatus

A Minnesota Impedance Cardiograph (Model 304B) was used to obtain both electrocardiogram (ECG) and impedance cardiogram (ICG) measures including basal thoracic impedance (Z_0) and the first derivative of the impedance signal (dZ/dt). ECG measures were obtained from three spot electrodes, one placed below the suprasternal notch on the participant's sternum and the remaining two placed over the fifth intercostal spaces on the participant's left and right sides. ICG measures were obtained by placing four Mylar tape electrodes around the participant's neck and torso in accordance with standard protocol (Sherwood et al., 1990).

Data Quantification

ECG and ICG data were sampled at 500 Hz using the ANS Suite 6.11 (Ernst, Litvack, Lozano, Cacioppo, & Berntson, 1999) data acquisition system. Mindware HRV 2.01 (Mindware Technologies, Columbus, OH) was used to analyze and check for artifacts in the ECG data. HP was used in the current analysis instead of heart rate because of its superior biometric properties when autonomic changes are of interest (Berntson, Cacioppo, & Quigley, 1995). HP was calculated as the average time (in ms) between successive R-R intervals. High frequency heart rate variability (HRV) was calculated using FFT of the resampled interbeat interval time series as the natural logarithm of the variance in the respiratory sinus arrhythmia (RSA; 0.13–0.40 Hz) frequency band (Berntson et al., 1997). Respiration rate in breaths/min and respiratory amplitude in arbitrary units were obtained from the dZ/dt data (Ernst et al., 1999). Impedance data were analyzed using Mindware IMP 2.0 software (Mindware Technologies). Systolic time intervals were obtained from the ensemble-averaged waveforms for ECG and dZ/dt across 1 min epochs. PEP was calculated as the time in ms between the peak of the ECG Q-wave and the B-point of the dZ/dt waveform (Sherwood et al., 1990). Change scores for each measure were computed by subtracting the baseline value from the task value for each participant.

Tasks

Digitized images of all visual stimuli were presented using SuperLab software (Cedrus, Inc.). Twelve illusions, black and white line drawings from Berntson et al. (1996), were selected for the present study because they could be presented as either illusions or nonillusions (e.g., figure/ground reversals, subjective contours, impossible figures, perceptual afterimages, etc). Nonillusory stimuli were created by altering the illusions so that they no longer appeared as an illusion while still retaining the image's complexity. In addition, half of the visual stimuli were paired with corresponding text directing the participant's attention to the illusory content of the figure, whereas the other half of the visual stimuli had no text. For instance, if the Müller-Lyer illusion was present, the corresponding text would read "Which line is longer?" In illusion-absent conditions, the Müller-Lyer illusion was modified by changing the arrowheads into perpendicular lines. Figure 1 illustrates how the Müller-Lyer illusion was presented in the practice trial for each group. The duration of the illusion task was 1 min

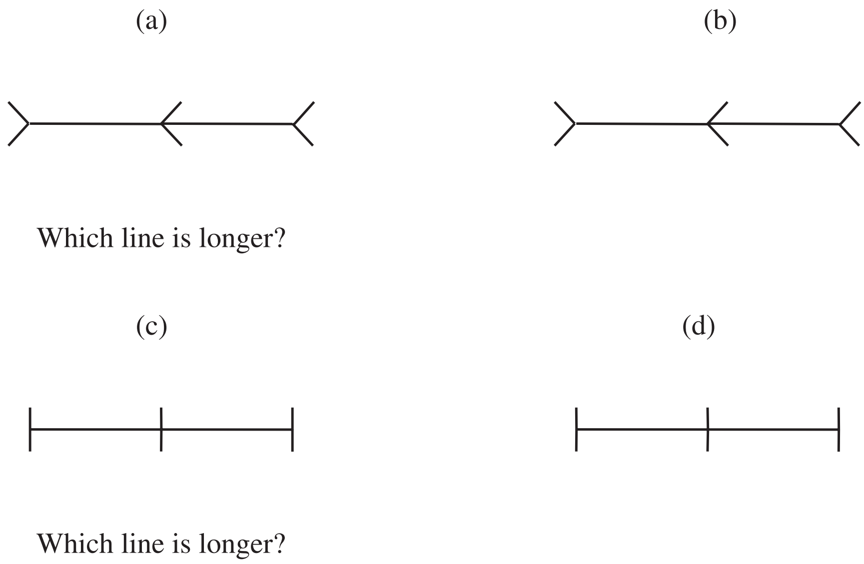

Figure 1. Sample visual stimulus for the Müller-Lyer illusion used in the practice trial for the four visual task groups: (a) illusion and text present, (b) illusion present and text absent, (c) illusion absent and text present, (d) illusion and text absent.

during which three visual stimuli were presented, each for 20 s. Visual stimuli were counterbalanced across participants. Participants in each group were told to simply attend to the visual stimuli across the 1 min trial.

Each group also participated in the same mental-arithmetic condition as was used in the Bernston et al. (1996) study. Mental arithmetic, also presented using the SuperLab software, was a serial subtraction task where participants were instructed to provide each answer as quickly as possible. The number to be subtracted, or subtrahend (3, 7, 8, or 13), was varied across participants. Each 1 min trial consisted of one subtrahend presented with three different 4-digit seed numbers each presented for 20 s. Participants were to verbally count backwards using the current subtrahend. For example, participants would be presented with "5678–7" and they were required to say aloud "5671," "5664," "5657" and so on until the next problem was presented. Participants were given immediate feedback by the experimenter when errors occurred and asked to begin with the last correct response.

Procedure

Participants gave informed consent and completed a brief demographic questionnaire. Participants sat 1 m from a 53.34 cm (21 in) monitor. Each participant read the instructions and was told to ask questions if needed. Two practice trials, one visual task and one mental arithmetic task, were provided before any psychophysiological measurements were made. The practice trials used different illusions and arithmetic problems from the test trials.

All participants began with a 1 min baseline during which they were asked to simply relax and focus upon the fixation cross located in the center of the computer monitor. Participants in each group then received either the visual task or the mental-arithmetic task, followed by the other task. The order of tasks was counterbalanced across participants, and a 1 min interval preceded the second task.

After the experiment, each participant filled out a brief questionnaire regarding their strategies and opinions about each task. In addition, participants assigned to groups receiving corresponding text with the visual stimuli were asked if the text clarified the stimuli. Finally, all participants were debriefed.

Results

All analyses were conducted using SPSS for Windows v11.5 (Green, Salkind, & Akey, 2000) with α set at .05. Initial one-way ANOVAs were performed across the four groups for the baseline values for each cardiac and respiratory measure and no significant differences were found (see Table 1). Therefore all further analyses were conducted on the change scores.

Nomothetic Analyses

Separate 2 (illusion: present/absent) × 2 (text: present/absent) between-participant ANOVAs were conducted on the change scores for each physiological measure from the visual task. For HP, there was a main effect of illusion, $F(1, 76) = 12.13$, $p = .001$, where HP lengthened from baseline when no illusion was present ($M = 20.25$ ms) and shortened from baseline when an illusion was present ($M = -13.66$ ms). There were no main effects or interactions across the illusion and question conditions for any other measure.

As a manipulation check, separate 2 (text: present/absent) × 2 (illusion: present/absent) between-participant ANOVAs were conducted on each physiological measure

Table 1. Mean *(SD)* baseline measures for the four visual task groups (n = 20)

	No question Illusion present	No question Illusion absent	Question illusion present	Question illusion absent
Cardiac measures				
HP (ms)	771 (156)	742 (126)	814 (125)	719 (114)
RSA (ln(ms^2))	6.122 (1.184)	6.076 (1.192)	6.767 (1.033)	5.922 (0.846)
PEP (ms)	89 (16.6)	92 (9.7)	89 (17.4)	85 (15.0)
Respiratory measures				
Rate (breaths/min)	15.4 (3.31)	16.7 (2.43)	16.8 (2.49)	16.7 (3.39)
Amplitude (arbitrary units)	0.015 (0.015)	0.021 (0.037)	0.016 (0.016)	0.026 (0.036)

Table 2. Mean *(SD)* baseline-corrected scores for the illusion-present (n = 40) and illusion-absent (n = 40) visual task groups and mental arithmetic task (n = 80) across all groups

	Visual task illusion present	Visual task illusion absent	Mental arithmetic
Cardiac measures			
HP (ms)	–13.66 (40.55)*	20.25 (45.30)**	–98.08 (62.34)**
RSA (ln (ms^2))	–0.15 (.76)	–0.03 (.91)	–0.37 (1.19)**
PEP (ms)	2.38 (5.33)**	2.95 (4.27)**	–1.99 (5.10)**
Respiratory measures			
Rate (breaths/min)	1.29 (3.48)*	0.25 (2.82)	2.37 (4.87)**
Amplitude (arbitrary units)	–0.002 (.01)	–0.004 (.03)	–0.008 (.03)**

Note: *p < .05, **p < .01 denotes significant differences from baseline

from the mental-arithmetic task. As expected, there were no main effects or interactions for the text and illusion factors for any measure.

Follow-up one-sample t-tests were conducted for all measures to determine if they differed significantly from baseline. Table 2 lists the mean change score and the standard deviation for each measure. Mean scores for the visual task are presented separately for the groups that received the illusions and for those that did not because the illusion factor was significant in the ANOVA for HP. When illusions were present in the visual task, HP significantly shortened, PEP lengthened, and respiratory rate increased from baseline. When illusions were absent, HP and PEP significantly lengthened.

As can be seen in Table 2, all measures differed from baseline in the direction predicted from the Berntson et al. (1996) study for the mental-arithmetic task where HP, RSA, and PEP decreased and respiration was faster and shallower than baseline. Because the respiratory measures changed significantly from baseline-to-task we conducted an analysis of covariance for RSA change using respiration rate and amplitude changes as covariates. RSA change during mental arithmetic was still significant even after the respiratory effects were removed, $F(1, 76) = 5.61$, $p < .02$, suggesting that the RSA change was a function of the task and not a concomitant of respiration.

In summary, our nomothetic results for the mental-arithmetic task replicated the findings from the Berntson et al. (1996) study of cardiac acceleration caused by reciprocally coupled sympathetic activation and vagal inhibition. However, our results did not replicate the Berntson et al. study for the visual task.

Idiographic Analyses

We conducted an idiographic analysis of autonomic modes of control because uncoupled sympathetic inhibition was the mode of control identified in the nomothetic analyses for both illusion-present and illusion-absent groups even though HP changed in opposite directions. The idiographic approach was adopted to examine how modes of control differed across individual participants during the visual and mental-arithmetic tasks. All 80 participants were considered in the analysis of the mental-arithmetic task, whereas the 40 participants in the two illusion-present groups and the 40 participants in the two illusion-absent groups were considered separately in an attempt to better understand the differences in HP patterns that emerged between the groups.

In Table 3, each participant's reactivity was categorized in autonomic space. A response was categorized as sympathetic inhibition when PEP change was more than 2 ms longer than baseline and as sympathetic activation when PEP change was more than 2 ms shorter than baseline. A response was categorized as vagal inhibition when RSA change was more than 0.1 ln(ms^2) below baseline and as vagal activation when RSA change was more than 0.1 ln(ms^2) above baseline. PEP change within ± 2 ms and

Table 3. Idiographic analysis of sympathetic and parasympathetic activity for mental arithmetic (top), illusion-present (middle), and illusion-absent (bottom) tasks. Table contains the percent of participants who exhibited each mode of autonomic control (individual cell percentages may not sum to row and column marginal totals because they were rounded to whole numbers)

Sympathetic activity	Parasympathetic activity			
	Activation	No change	Inhibition	
Mental arithmetic ($N = 80$)				
Activation	19	6	30	55
No change	8	1	8	16
Inhibition	4	5	20	29
	30	13	58	
Illusion-present ($N = 40$)				
Activation	8	3	13	23
No change	13	3	10	25
Inhibition	23	8	23	53
	43	13	45	
Illusion-absent ($N = 40$)				
Activation	5	0	13	18
No change	8	5	10	23
Inhibition	33	10	18	60
	45	15	40	

RSA change within ± 0.1 $\ln(\text{ms}^2)$ were categorized as no change from resting baseline[1].

The upper panel of Table 3 illustrates the distribution of the 80 participants within the nine possible modes of autonomic control in the mental-arithmetic task. The nomothetic analysis indicated that the mode of control for this task was reciprocally coupled sympathetic activation and vagal inhibition. Twenty-four participants (30.0%) were classified as having reciprocally coupled sympathetic activation and vagal inhibition during the task, representing the greatest number of participants. Fifteen participants (19%) showed coactivation and 16 participants (20%) showed coinhibition. Each of the other modes was represented by less than 8% of the sample. A χ^2 was conducted on the 3 × 3 contingency table (see Table 3), however, there was no significant difference among cell frequencies, $\chi^2(4, N = 80) = 5.25, p > .05$. Thus, individual results from participants varied across all autonomic control modes even for the mental-arithmetic task where the nomothetic response was quite robust.

For the visual task, separate idiographic analyses were conducted for illusion-present and illusion-absent groups. Both illusion-present and illusion-absent groups had a clear nomothetic pattern of sympathetic inhibition over sympathetic activation. As seen in Table 3, the illusion-present group had 21 participants (52.5%) who showed sympathetic inhibition as compared to 9 participants (22.5%) having sympathetic activation. A similar pattern emerged in the illusion-absent groups with 24 participants (60%) who showed sympathetic inhibition compared to 7 participants (17.5%) having sympathetic activation.

A less clear-cut pattern emerged for parasympathetic activity within the visual task. In the illusion-present groups, 18 participants (45%) exhibited vagal inhibition whereas 17 participants (42.5%) exhibited vagal activation. Likewise, in the illusion-absent groups, 16 participants (40%) exhibited vagal inhibition whereas 18 participants (45%) exhibited vagal activation. Finally, separate χ^2 analyses were conducted on the 3 × 3 contingency tables for the illusion-present and illusion-absent groups, both of which failed to reach significance.

In summary, despite finding significantly lengthened PEP without obtaining a significant change in RSA within the visual task, it is premature to classify the autonomic mode of control for the visual task as uncoupled sympathetic inhibition for several reasons. First, the different patterns of HP response observed in illusion-present (shortened HP) and illusion-absent groups (lengthened HP) cannot both be accounted for by an uncoupled sympathetic inhibition mode of control, which should elicit lengthened HP. Second, it was apparent from the idiographic analyses that changes in parasympathetic response did occur in the majority of participants, with vagal activation or inhibition occurring about equally often. For the illusion-absent group, the idiographic analysis revealed that the largest subgroup of participants ($N = 13$; 32.5%) exhibited a reciprocally coupled sympathetic inhibition/vagal activation mode of control. This mode is consistent with the increase

[1] The category cutpoints were chosen because they exceeded the measurement error for PEP and RSA. Alternative classification schemes based upon percentiles (e.g., tertiles) were examined. Because the proportions assigned to each category were similar across classification schemes, we used the physical units as they would not change across samples.

in HP that occurred in the illusion-absent groups. In contrast, for the illusion-present group, an equal number of participants showed either nonreciprocally coupled coinhibition (22.5%) or reciprocally coupled sympathetic inhibition/vagal activation (22.5%). The coinhibition mode can be consistent with the obtained HP shortening, however the reciprocal vagal activation mode of control is not.

Postexperimental Questionnaire

Participants were asked to rate how interesting the mental arithmetic and visual tasks were on a 6-point Likert scale ranging from 1 *not interesting* to 6 *very interesting*. Similar questions regarding each task's difficulty were also asked using a scale ranging from 1 *not difficult* to 6 *very difficult*. Finally, for those participants who received the corresponding text in the visual task there was a fifth question regarding the extent to which the text aided in clarifying the image rated on a scale ranging from 1 *not at all* to 6 *very much*. Two participants failed to answer every question on the postexperimental questionnaire, so the degrees-of-freedom differ across analyses.

A paired t-test comparing the visual and mental-arithmetic tasks was performed for the difficulty and interest questions. The mental arithmetic task ($M = 4.30$) was rated as more difficult than the visual task ($M = 2.23$), $t(79) = -12.04$, $p < .001$. Participants tended to rate the visual task ($M = 4.06$) as more interesting than the mental arithmetic ($M = 3.71$), $t(79) = 1.75$, $p < .09$.

A 2 (illusion) × 2 (text) ANOVA was conducted on the interest and difficulty ratings for the visual task. A main effect of illusion was obtained such that the illusion-present group ($M = 4.40$) rated the visual task as being more interesting than the illusion-absent group ($M = 3.73$), $F(1, 76) = 5.79$, $p < .02$. In addition, a main effect of text was obtained where groups receiving text rated the stimuli as more interesting ($M = 4.45$) than those not receiving text ($M = 3.68$), $F(1, 76) = 7.64$, $p < .007$. Difficulty was not found to differ significantly between illusion-present ($M = 2.43$) and illusion-absent groups ($M = 2.03$); however, a main effect of text was obtained where groups receiving text rated the visual task as more difficult ($M = 2.50$) than groups not receiving text ($M = 1.95$), $F(1, 76) = 4.03$, $p < .05$. Finally, participants receiving text in the illusion-present group found the text more useful ($M = 5.10$) than those who received text in the illusion-absent group ($M = 4.33$), $F(1, 36) = 5.60$, $p < .03$.

Discussion

Although the current findings for the mental-arithmetic task replicated the Berntson et al. (1996) study, where the majority of participants exhibited reciprocally coupled sympathetic activation and vagal inhibition resulting in shortened HP, the findings for the visual task did not. The mode of autonomic control observed during the visual-illusion task in their study was uncoupled vagal activation that resulted in lengthened HP. In the current study, our nomothetic analyses found that an uncoupled mode of sympathetic inhibition occurred in the visual task, and that this mode of control did not differ across groups that saw illusory or nonillusory stimuli with or without text. It is interesting to note that Bernston et al. also found sympathetic inhibition in their illusion task, but it was not statistically significant.

An uncoupled sympathetic inhibition mode of control should lengthen HP in the visual task groups; however, HP change differed between illusion-present and illusion-absent groups. For illusion-absent groups, lengthened HP was observed that is consistent with visual-attention tasks requiring minimal cognitive effort (Berntson et al., 1996; Lacey & Lacey, 1974). Contrary to our prediction, shortened HP was observed for the illusion-present groups, even though illusions were rated as more interesting than nonillusions. Previous research found that stimuli rated as more interesting were associated with greater HP lengthening (Libby et al., 1973).

Therefore, the illusions may have resulted in cardiac acceleration because cognitive/effortful processing occurred while attending to the stimuli. Visual illusions appear to be largely dependent upon the resolution of nonconverging bottom-up (data-driven) and top-down (conceptually-driven) inputs (Gregory, 1997; Gunn et al., 2000; Spillmann & Dresp, 1995; Vecera & O'Reilly, 1998). Nonillusory stimuli are also subjected to both bottom-up and top-down processing for object recognition to occur (Coren, Ward, & Enns, 1999; Sekuler & Blake, 1994). However, the discrepancy created by top-down and bottom-up processing with illusions may require additional cognitive effort to integrate these two types of processing, which may manifest in cardiac acceleration.

Although the mean difficulty rating was higher for the illusion-present than the illusion-absent group, the difference was not significant indicating that any additional cognitive effort for illusions in the present study was not evident at the subjective level. However, Pritchard and Warm (1983) used dual-task methodology to measure the degree to which top-down processing differed between subjective contour illusory stimuli (versions of the Kanizsa triangle) and comparison stimuli that had real contours. They found that participants' performance on a secondary memory task was significantly impaired during same judgments of illusory stimuli compared to same judgments of nonillusory stimuli using this more sensitive method of assessing cognitive effort. Thus, at least for subjective contour illusions, top-down processing seems to play a greater role when attending to illusory than nonillusory stimuli, which is consistent with our finding of shortened HP for the illusion-present groups.

Because of the inconsistency between the purported mode of autonomic control and shortened HP for the illusion-present group, it is important not to draw conclusions regarding the neural control of the chronotropic cardiac response to visual stimuli based upon the nomothetic data. The idiographic analyses were conducted to better determine how participants were responding to the visual task. These analyses found that there was no association between sympathetic and parasympathetic responding in the visual task (or in the mental-arithmetic task), even though there were significant nomothetic effects for both tasks. Berntson et al. (1996) also found substantial individual differences in the autonomic control modes for both their illusion and mental-arithmetic tasks, although they found that sympathetic and parasympathetic changes were significantly correlated in their mental-arithmetic task (PEP and RSA $r = .50$, $p < .05$) and not in their illusion task (PEP and RSA $r = -.34$). In the present study, sympathetic and parasympathetic change were not significantly correlated for either our mental-arithmetic task (PEP and RSA $r = .15$) or our illusion task (PEP and RSA $r = .15$). The fact that PEP and RSA were not significantly correlated in the mental-arithmetic task suggests that our sample may have been more heterogeneous than the Berntson et al. sample. For example, although there was a clear pattern of sympathetic inhibition rather than activation in both the illusion-present and illusion-absent groups, there were an approximately equal number of participants demonstrating vagal activation or vagal inhibition. In contrast, Berntson et al. found predominantly vagal activation in the idiographic analysis in their illusion task, which was consistent with their nomothetic finding.

Despite the failure of the idiographic analyses in the present study to find that the preponderance of participants were classified as exhibiting the mode of control identified in the nomothetic analyses, 73% of participants in the illusion-absent groups exhibited a mode of control that could be consistent with lengthened HP (i.e., reciprocally coupled sympathetic inhibition and vagal activation, uncoupled vagal activation, uncoupled sympathetic inhibition, coactivation, or coinhibition). In comparison, only 55% of the participants in the illusion-present groups were classified as exhibiting a mode of control that could be consistent with shortened HP (i.e., reciprocally coupled sympathetic activation and vagal inhibition, uncoupled sympathetic activation, uncoupled vagal inhibition, coactivation, or coinhibition). Such diverse patterns of autonomic modes of control suggest that measures of individual differences may be needed to better account for autonomic reactivity patterns (Marwitz & Stemmler, 1998).

For instance, individuals with certain personality traits, such as the need for cognition (Cacioppo & Petty, 1982), may be more likely to use more cognitive effort, which may influence how they perceive visual stimuli (Koch & Hayworth, 2003). In addition, because no overt responses were required, it is unknown how long participants attended to each stimulus. Each stimulus was presented for 20 s during which participants could have stopped attending to the task. Indeed, terminating attention has been shown to result in a return to baseline after an attention-driven cardiac deceleration (Jennings et al., 1991). Also, Koch and Hayworth noted that response latency may be related to the need for cognition, where those high on this dimension would be expected to take longer to process the illusion. This suggests that those high in need for cognition may stay engaged in processing the stimulus longer, and vice versa for those low in need for cognition, resulting in widely varying individual responses as were seen here.

In conclusion, attending to illusory visual images elicited different HP change than attending to nonillusory visual images. The HP change that emerged in illusion-absent conditions was consistent with the cardiac deceleration found in earlier attention studies (Berntson et al., 1996; Lacey & Lacey, 1974; Libby et al., 1973). We suspect that the nomothetic cardio-acceleratory response to illusions occurred in part because of increased cognitive effort needed to resolve top-down and bottom-up processes. Illusions vary to the extent that they elicit top-down processing, and it may be that cardiovascular reactivity differs between primarily top-down visual illusions (i.e., figure/ground reversals and subjective contours) and primarily bottom-up visual illusions (i.e., perceptual afterimages). Both types of illusions were used in the Berntson et al. study and in the current study, which probably contributed to the individual differences in autonomic control modes for the visual task.

Finally, it is not clear why the text manipulation had no discernable effect upon the cardiovascular and respiratory measures in the present study. The postexperimental questionnaire revealed that the groups that had text found the visual stimuli to be significantly more interesting (consistent with our prediction) and more difficult (contrary to our prediction) than the groups that had the visual stimuli without text. Further, the illusion-present group found the text to be more useful than the illusion-absent group. Perhaps the combination of cardio-deceleration with greater interest and cardio-acceleration with greater cognitive effort merely served to increase the individual differences to the text manipulation in the same way as top-down/bottom-up processing may have contributed to individual differences to the illusion manipulation. Or perhaps reading is such an automatic process that the cardio-respiratory measures of attention were insensitive to the short text phrases used to describe the illusions.

A limitation of the present experiment was that only a single 1-min trial of each condition was presented. Future studies should include more trials to be able to examine the stability of the individual differences found for the autonomic modes of control in the idiographic analyses. Our speculation about cardiovascular reactivity to illusions that require top-down vs. bottom-up processing should also be examined in future studies, perhaps using dual-task methodology such as Pritchard and Warm (1983). Further, future studies should include ways to examine the contributions of individual difference factors such as the personality trait of the need for cognition. Another such factor to consider may be a participant's familiarity with the illusory stimuli.

For example, Girgus and Coren (1973) found that, although it was still present, the Müller-Lyer illusion decreased in magnitude with exposure duration across a 5-min viewing period. Because our participants were enrolled in a psychology class, they may have seen some of the illusions before, which may have reduced the impact of those illusions.

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