To what extent can simple contextual events affect preference? In this study, three tests were applied to assert whether contextual unpredictability has a negative effect on preference for novel visual items. By asking subjects to rate their first impressions of novel brand logos while playing simple sounds, Study 1 shows that brand logos coupled to unpredictable sounds were rated less favorably than logos presented with a predictable sound. In Study 2, this effect is found to be equally strong for abstract art paintings. Finally, Study 3 demonstrates that the negative effect of unpredictable sounds on preference is associated with a stronger arousal response, as indexed by pupil dilation responses. These results suggest that unpredictable sounds engage an emotional response that affects the first impression of a concurrently presented visual object. We discuss these findings in light of the basic psychology and neuropsychology of preference formation.

Keywords: first impression, neuroscience, pupil dilation, arousal, emotion, preference formation

Preferences are well known to be affected by contextual factors. Indeed, the very foundation of prominent theories of decision making, such as Behavioral Decision Theory, has been the realization that rationality is bounded, that is, that preferences and decisions are influenced by contextual factors. In particular, factors such as risk and ambiguity have been shown across different situations to affect reported and revealed preferences (Kahneman & Tversky, 1979; Christopoulos et al., 2009). For example, gambles with known risks are preferred to gambles with unknown (ambiguous) risks, a factor that has been related to increased engagement of brain regions associated with aversion responses (Levy et al., 2010). Similarly, ambiguity aversion has been shown to systematically lead to a favoring of established brands to novel brands (Muthukrishnan, Wathieu & Xu, 2009). Although studies of preference and decision making treat uncertainty and ambiguity as higher mental processes—as found in financial decisions (Critchley, Mathias & Dolan, 2001), gambling (Bechara, Damasio & Damasio, 2000; Fukui et al., 2005), and multiattribute product choices (Muthukrishnan, Wathieu & Xu, 2009)—studies have also suggested that similar effects can occur at more basic perceptual levels. For example, in the case of the well-known mere exposure effect preference increases with repeated exposures (Janiszewski, 1993; Monahan, Murphy & Zajonc, 2000), and has been shown across a variety of situations, including the subliminal level. Indeed, the mere exposure...
effect demonstrates that preferences can be affected by purely perceptual mechanisms.

Little is still known about the fundamental psychological mechanisms underlying the effects that ambiguity and uncertainty has on preference, judgment, and choice. However, with the rise of modern cognitive neuroscience new possibilities have emerged for assessing the immediate perceptual, cognitive, and emotional mechanisms by which preference can be affected. Thus, studies have demonstrated that visual processing and emotion are related in a way such that perceptual features can influence the neural activity of brain structures thought to underlie emotional processing (e.g., Bechara, Damasio & Damasio, 2000; Delgado et al., 2008). In the same way, emotional responses to objects have been shown to modulate activity in the visual system. For example, the subjective valence of an object affects how attentional resources are allocated to perceptual processing of it. Thus, compared with neutral stimuli, more attentional resources are allocated to the perceptual computation of emotional, especially negative, objects (Öhman & Mineka, 2001; Algom, Chajut, & Lev, 2004; Estes & Verges, 2008), as demonstrated by an increase in detection accuracy (Nasrallah, Carmel, & Lavie, 2009).

As noted, the mere exposure effect shows that repeated exposure to a stimulus increases the preference for it compared with how well the same object is liked as a previous unfamiliar stimulus (Zajonc, 1968). In other words, a mere difference in perceptual exposure to an object is enough to enhance its perceived value, suggesting that the valuation process underlying the generation of preferences for experienced objects is not only susceptible to the content of what is sensed, but also to the sensory manner in which they are experienced. It remains unclear, however, exactly how changes in perception, as witnessed by the mere exposure effect, influence valuation processing, but one possible explanation, already put forward by Zajonc (1980, 2001), suggests that early perceptual computation signals affective structures to inform the brain quickly and automatic of possible biologically relevant changes to the environment. For example, unexpected changes could be sign of the sudden appearance of dangerous predators that would require swift action. The functional advantage of a perceptual system being able to provoke a fast affective response would be quick changes in motivation for behavior without the brain having to cognitively represent and recognize what object it is in fact dealing with (Changizi, & Shimojo, 2008). Hence, it makes sense for unknown, novel, and unpredictable perceptual stimuli to be somewhat negatively colored by the brain’s valuation system. As proposed by Zajonc, the reason why further exposure to an object leads to increased liking can be explained by the affective system signaling that the object turned out not to be dangerous after all. This explanation is supported by evidence that the mere exposure effect is larger when the stimulus is perceived without awareness (Bornstein, 1989; Bornstein, & D’Agostino, 1992), and that schizophrenia patients that exhibit impaired performance on explicit memory tasks show a normal mere exposure effect (Marie et al., 2001), suggesting that the impact of exposure on preference formation is attributable to unconscious, nonrepresentational processing. The latter point is further buttressed by studies showing that subliminal, affective primes can influence consumptive behavior, even when subjects experience no changes in conscious feelings (Winkielman, Berridge & Wilbarger, 2005). Indeed, although studies have focused on the possible role of subliminal cues in motivating subjects to approach goods and products (Veltkamp, Martijn & Aarts, 2011), and their limitations (Verwijmeren et al., 2011), little is known about the potential adverse effects that subliminal cues can have on preference and choice.

Support for this scenario can be found in recent neuroscience research that demonstrates that the perceptual systems of humans and animals are sensitive to alterations in the physical features of the surrounding sensory world, and that their affective systems are modulated by the sensory probability of an perceptual event (Kagan, 2009). Faced with some event that alters the immediate sensory surround, human brains will produce emotional reactions reflecting this unexpectedness. Specifically, brain structures important for generating negative emotions and avoidance behavior respond more strongly to novel relative to familiar information (Kiehl et al., 2001; Petrides, 2007; Wright et al., 2003). However, after repeated exposures such responses tend to decline (Yamaguchi, Hale, D’Esposito, & Knight, 2004).
A key brain structure thought to mediate the interaction between perception and emotion is the amygdala (Winkielman, Knutson, Paulus, & Trujillo, 2007; Pessoa & Adolphs, 2010). Amygdala activity has been demonstrated to predict preference for low-level perceptual properties, including an object’s contour, in such a way that higher activity appears to reflect lower preference (Bar & Neta, 2007). A possible explanation for this phenomenon is that the amygdala reflects the salience or biological relevance of a perceptual event. Support for this hypothesis comes from studies that show that amygdala activity reflects a difference of impact of negative emotional images matched for valence and arousal (Ewbank et al., 2009), or from studies showing that just listening to an unexpected chord in a musical sequence elicits higher amygdala activation and lower preference (Koelsch, Fritz & Schlaug, 2008). In other words, the impact of amygdala activity on preference formation may be explained, in part at least, by its sensitivity to environmental contingencies in such a way that salient events, including precisely unfamiliar stimuli, provoke a negative affective response which might be modulated in positive manner as the salience of the event changes, for instance through exposure.

Recent neuroimaging research has revealed that, indeed, the neural structure amygdala plays a pivotal role in computing emotional responses to perceptual expectedness. Several lines of evidence suggest that amygdala activity is sensitive to environmental contingencies and that changes in amygdala activity influences preference formation (e.g., Fischer et al., 2003; Ramsøy & Skov, 2010; Schwartz et al., 2003; Wright et al., 2003). Salient events, including unexpected stimuli, provoke a negative affective response, which might be modulated in positive manner as the salience of the event changes, for instance through exposure.

Recent neuroimaging research has revealed that, indeed, the neural structure amygdala plays a pivotal role in computing emotional responses to perceptual expectedness. Several lines of evidence suggest that amygdala activity is sensitive to environmental contingencies and that changes in amygdala activity influences preference formation (e.g., Fischer et al., 2003; Ramsøy & Skov, 2010; Schwartz et al., 2003; Wright et al., 2003). Salient events, including unexpected stimuli, provoke a negative affective response, which might be modulated in positive manner as the salience of the event changes, for instance through exposure.

Based on these previous findings and theories, it is reasonable to assume that unpredictable factors can affect emotional responses and judgments. In particular, it is possible that such influences can work across different sensory domains, such as audition and vision. Based on this assumption, we hypothesize that contextual unpredictability is associated with lower preference for simultaneously presented information (H1).

To further qualify this effect, we suggest three additional hypotheses. If, as assumed, contextual unpredictability affects emotional responses and preferences, this effect should exist across different domains. Thus, we propose that contextual unpredictability will be associated with lower preference across different visual domains (H1a). Furthermore, although the study by Herry et al. (2007) demonstrated that
specific emotional brain structures, such as the amygdala, were more engaged by unpredictable sounds, this finding was not related to changes in physiological arousal and in itself provides little insight into the relationship between physiological arousal and emotional judgment. Based on this, we suggest two additional hypotheses: contextual unpredictability is related to increased physiological arousal (H1b), and that physiological arousal, when affected by contextual unpredictability, is negatively related to emotional judgment (H1c).

To test these hypotheses, we conducted three experiments. The first two studies tested the effect of contextual predictability—by using predictable and unpredictable sounds—on emotional preference for novel cultural objects such as brand logos and abstract art paintings, respectively. The third study used high-resolution eye-tracking to test the effect of contextual predictability on physiological arousal and its effect on subsequent preference ratings.

**Study 1: Sound Ambiguity and Preference for Novel Brand Logos**

If the general hypothesis is correct, one should observe preferences for objects vary when evaluated in situations where perceptual expectedness vary. The experimental paradigm developed by Herry and his colleagues (2007) unequivocally demonstrated that an unexpected sound sequence produced increased activation of the amygdala compared with an expected sound sequence, and that this neural effect was accompanied by elevated avoidance behavior both in humans and mice. If it is this neural mechanism that explains the mere exposure effect, we should observe higher preference ratings for novel brands when they are evaluated during perceptual predictability than when evaluated during perceptual unpredictability. To test this prediction we randomly assigned subjects to a two (sound: unpredictable or predictable) by four (brand logo category: cosmetics, electronics, finance, beer) factorial design study. Using the set-up from the Herry et al. (2007) study we presented unknown brand logos with either unpredictable or predictable sounds, and hypothesized that the logos perceived under the first condition would receive lower preference ratings than logos perceived under the latter condition.

Sixty subjects (38 women, age mean/standard deviation = 25.4/2.9, 52 right-handed) underwent experimental testing. All subjects were exposed to a total of 60 images of previously unknown brand logos, selected from a database of unused and unknown brand logos (www.brands-of-the-world.com). An equal number of brand logos from four different categories were used: cosmetics, beer, electronics, and finance. All stimuli were presented on a computer screen running E-Prime 2.0 (www.pstnet.com) in a Microsoft Windows XP environment. Visual stimuli were presented on a CRT monitor (resolution = 800 x 600 pixels; refresh rate = 85 Hz; average viewing distance = 60 cm). Sounds were presented through headphones (Sennheiser HD 555). Subjects responded using the numeric buttons on a computer keyboard.

For each trial, subjects first saw a white fixation cross on a black background. After 1 second, a predictable/unpredictable sound was played for 4 seconds. One second into the sound presentation, subjects saw a brand logo on the screen for 3 seconds. Thus, there was an overlap between sound stimulus and brand logo image for 3 seconds (see Figure 1). Among the total of 60 logo images, half (30) were randomly paired with the single predictable sound, and each of the other half was paired with one of the 30 unpredictable sounds. Following this, subjects were asked to rate their liking for each brand logo, using an on-screen five-point Likert scale (range: 1 = strongly dislike, 5 = strongly like). Response times were self-paced, that is, the test would only continue after the subject had responded. Responses and RTs were logged using E-Prime 2.

We constructed one predictable and 30 unpredictable sounds with a duration of 4 seconds, following the method outlined in Herry et al. (2007). Predictable sounds were made with a carrier frequency of 1 kHz with pulse duration of 40 ms and a pulse spacing of 200 ms (5 Hz pulse repetition rate). Unpredictable sound pulse sequences were constructed by applying a random jitter to the timing of the sound pulses, with a maximum offset of ± 60 ms. The sound pulse time series was derived by randomly varying pulse timing within defined temporal boundaries of predictable sound pulse sequences with regular pulse timing. The sound pulse was switched on and off smoothly using...
cosine-shaped increasing and decreasing ramps with a duration of 5 ms.

The statistical analysis first focused on the a priori hypothesis, by using a linear mixed effect (variance component) model. The dependent variable was liking response, with sound type (predictable, unpredictable) as independent variable, using subject as a random factor. To test for effects of sound on reaction time (RT), we also used the same linear mixed model analysis with RT as a dependent variable. Responses with a lower response time than 150 ms were excluded. Because we used a directional hypothesis, we performed a one-tailed test of significance.

After this analysis, we performed exploratory analyses by including additional variables and their interactions. Here, we used a linear mixed model, with gender (male, female), sound type (predictable, unpredictable), brand logo category (electronic, finance, cosmetics, beer; see Figure 2), and with subject as a random factor. We used a stepwise backward elimination procedure to obtain an optimal explanatory model of liking ratings. All analyses were run in R version 2.1.0 (http://cran.r-project.org/).

Results

The main effect of sound compared the relationship between sound type with preference responses. The mixed effects analysis confirmed the directional hypothesis: brand logos accompanied by unpredictable sounds were
rated significantly lower (mean/std = 2.37/0.07) than logos accompanied by predictable sounds (mean/std = 2.43/0.07; \( t = 1.72, p = .043 \)). The effects are also displayed in Figure 3.

There was no significant difference in RT between the sound types (unpredictable = 0.146 ± 0.002 ms; predictable = 0.146 ± 0.002 ms, \( t = 0.049, p = .961 \)), indicating that there were no differences in processing demand between the two sound types.

In our exploratory mixed model analysis we initially included variables (sound type, brand type, gender, and with subject as random factor) and their interactions and used a stepwise backward elimination procedure. The final model included image type, gender, and the gender by image interaction effect (see Table 1).

The observed gender effect, taking sound effects into account, was driven by a more positive rating by men (mean/std = 2.640/0.116) compared with women (mean/std = 2.256/0.088, \( p = .011 \)). Performing pairwise comparisons of brand logo categories, as Table 2 illustrates, revealed that beer logos received the highest ratings, followed by cosmetics, bank, and finally electronics logos. An analysis of the effects of brand category on RT showed no significant effect, suggesting that the effects of brand category were not the result of increased cognitive processing demand.

Finally, the study of interaction effects between gender and brand logo category revealed that besides the main effect higher ratings in men on all logos, the difference in preference for the two genders were particularly pronounced for beer and cosmetics logos.

Discussion

The aim of Study 1 was to test the extent to which contextual unpredictability could affect preference for simultaneously presented information. In particular, we were interested in testing whether unpredictability within one domain (audition) could affect emotional processing of information in a different domain (vision). In this first study, we demonstrate that the hedonic judgment of unknown brand logos is affected by a simultaneously played sound. If the sound was unpredictable, subjects’ judgments of brand logos were significantly lower than if the accompanying sound was predictable. This finding is in line with the recent study by Herry et al. (2007), in which the perception of unpredictable sounds, which led to an increased engagement of the mygdale, was associated with avoidance behaviors. Taken together with our data, in which we used identical sound stimuli, this suggests that contextual unpredictability engages the brain’s aversion circuit, and that this effect affects the subsequent emotional processing of simultaneously occurring information. Our results are in line with studies demonstrating adverse effects of contextual variables such as auditory and visual noise on cognitive performance and emotions (Nagar & Pandey, 1987; Haines et al., 2001; Schupp et al., 2008). For example, in a study by Keizer, Lindenberg, and Steg (2008) it was shown that environmental noise and disorder would affect people to act more disorderly and immoral. Our results provide a more detailed insight into these effects by suggesting that the immediate effects of contextual noise is an increase in aversive emotional responses that affect simultaneously presented information.

Notably, the results in this first study demonstrate that the effects of contextual predictability on preference is limited, and that it is overshad-
owed by other, larger effects such as logo type and gender. Nevertheless, although such effects were small, the use of a seven-point Likert scale may also have limited the sensitivity of the scale for detecting subtle changes in preference. Furthermore, our study only used sound as the carrier for stimulus predictability, and thus further research would be needed to test the effect in other sensory domains.

It should also be noted that our observations are relative differences between predictable and unpredictable sounds. Therefore, the data should be interpreted with some caution, as the results from Study 1 do not provide information about the directionality of the effects. However, as we shall see, when we explore the emotional responses to the manipulations (Study 3), we find additional evidence for directionality.

The observed effects in Study 1 may be the result of a unique combination of contextual cues and visual information. To better understand the generalization of the effects of contextual unpredictability on emotional processing, we wanted to test whether other kinds of visual information would be affected similarly to novel brand logos. To this end, we con-

Table 1  
Effects of Category, Gender, and Interaction on Preference Judgments

<table>
<thead>
<tr>
<th>Variable</th>
<th>df</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>(3:3366.231)</td>
<td>79.397</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gender</td>
<td>(1:57.977)</td>
<td>6.971</td>
<td>0.011</td>
</tr>
<tr>
<td>Category * Gender</td>
<td>(3:366.231)</td>
<td>5.119</td>
<td>0.002</td>
</tr>
</tbody>
</table>

*Note.* Results from exploratory analysis using backward stepwise regression, demonstrating main effects of brand category, gender, and their interaction.
constructed a second study, in which we tested the
effect of sound predictability on the emotional
judgments of abstract art.

Study 2 – Sound Ambiguity and Judgment
of Art

The experimental set-up was the same as in
Study 1. The same 60 subjects were used, but
instead of 60 images of brand logos in this study
we used 60 abstract paintings, taken from vari-
ous Internet resources. These 60 paintings were
selected from a larger pilot session of 200 im-
ages, which were rated for aesthetic liking by a
separate group of 10 subjects. The 60 images
with middle ratings across these subjects were
chosen. As in Study 1, the paintings were pre-
sented for 3 seconds, followed by a self-paced
rating task, in which subjects used a Likert scale
to report their subjective liking of the image
(range 1–5, where 1 = strongly dislike, 5 =
strongly like). Sound stimuli were presented 1
second before image onset, with a duration of 4
seconds.

As with Study 1, we analyzed the data using
a linear mixed model with liking as the depen-
dent variable, and with sound type as the inde-
pendent variable and subject as random factor.
The analysis was run using R version 2.1.0.

Results

Rating during unpredictable sounds (mean ±
std = 2.84 ± 0.03) were significantly lower
than ratings during predictable sounds (2.96 ±
0.03), t = 3.04, df = (1; 3362.5), p = .0012, and
the effects are displayed in Figure 4. In an
explorative analysis we included subject as ran-
dom factor, to abate the effects of individual
preferences for art. In doing so, we find an even
stronger effect (t = 3.4, p = .0007), and with
the model explaining a quarter of all the varia-
tion in the ratings (R² = 0.252). There was no
effect of sound type on response time (predict-
able = 850 ± 21 ms; unpredictable = 856 ± 22
ms, t = 0.21, p = .835).

Discussion

The aim of Study 2 was to test to what extent
the effect of contextual contingency on prefer-

![Figure 4](tapaid5/nec-npe/nec-npe/nec00412/nec0060d12z xppws S1 10/8/12 16:44 Art: 2012-0089)
ence for brand logos would work on a different visual domain, such as abstract art. The study conclusively demonstrates that sound predictability also shows similar effects on preference for other visual elements. Indeed, compared with the relative small effects seen in Study 1, sound predictability had a robust effect on preference for abstract art. While caution should be exercised for such findings in which there is no direct comparison between the two conditions, one possible explanation could be that the two conditions differed on at least two parameters. On the one hand, the abstract art paintings could have a wider range of layouts, as opposed to a relatively more constrained visual appearance seen in brands. This would induce more variability in ratings of art, and thus a larger space from which effects of sound predictability could be detected. Second, one may contend that at a more social—and even societal—level, judgment of abstract art may be seen as a more individualistic assertion than brand logos. This could induce a stronger variability in ratings for art images, thus producing a broader range of preference data for detecting changes induced by sound predictability.

Despite using identical stimuli to that of Herry et al. (2007), in which there was a significant engagement of the amygdala, the use of such stimuli under other conditions could still lead to differences in emotional processing. To test whether the use of unpredictable sounds lead to emotional arousal in our experimental conditions, we therefore ran a third study in which we assessed subjects’ physiological arousal to predictable and unpredictable sound stimuli, and subsequent sound plus visual combinations. Besides demonstrating that our use of contextual predictability worked in our experimental set-up, we could also learn more about the physiological bases of the effects we observed.

**Study 3 – Effects of Contextual Ambiguity on Arousal and Preference Judgments**

In our third and final study, we wanted to test to what extent the effect of sound unpredictability on preference would be associated with changes in arousal. If, as shown by Herry et al. (2007), unpredictable sounds are associated with increased amygdala activation and avoidance behavior, it stands to reason that other measures of arousal will show similar deflections. It is well established in the neuroscientific and neurophysiological literature that the amygdala is involved in the regulation of bodily responses such as facial expressions, pulse, respiration, sweating, and pupil dilation (De Martino, Camerer, & Adolphs, 2010; Groeppel-Klein, 2005; Steinmetz, Addis & Kensinger, 2010). As such responses tend to be collinear (Bradley et al., 2008), using one measure would suffice as an index of arousal.

By using high-resolution eye-tracking we sought to test whether unpredictable sounds would lead to a higher arousal responses, as indexed by pupil dilation, and thus test H1b. If, as assumed, unpredictable sounds are associated with negative emotional responses, this would also lead to stronger pupillary responses, when compared with predictable sounds. Furthermore, the use of pupil dilation in our experimental set-up would also serve as a validation of the main method in demonstrating the involvement of arousal as a main factor in our behavioral effects.

**Method**

Eighteen right-handed subjects (age 24.8 ± 5.3 years, eight women) with normal or corrected to normal vision were recruited from the Copenhagen region. Based on a self-report questionnaire, no subject experienced, or had any indication of, neurological or psychiatric disease. All subjects provided informed consent.

High-resolution eye-tracking was performed using a Tobii T60 XL tracker running at 60 Hz with a 1920 × 1200 pixel screen resolution and an approximate viewing angle of 60 cm. Stimulus presentation and the recording of subject responses and eye tracking data were performed using Attention Tool version 4.5 (iMotions Inc., www.imotionsglobal.com).

After undergoing a nine-point eye tracking calibration procedure, subjects performed the same experimental task as in the two prior studies; after a first second of exposure to a predictable or unpredictable sound, a novel brand logo was shown for 3 seconds while the same sound continued. The sound stimuli were identical to the prior studies, and used pseudorandomly with brand logos, and in which sound-image coupling was counterbalanced across subjects.
As in the prior study using brand logos, we used four categories of brand logos (finance, cosmetics, beer, and electronics). Subjects rated their preference for the brand logo using an analogue scale on screen using a computer mouse.

All data were analyzed using JMP version 9.0 (SAS Inc.). We first analyzed the effects of sound type on preference ratings by running a general linear model (GLM) analysis with ratings as the dependent variable, using sound type (predictable, unpredictable) as the independent variable, and with subject as random factor. To analyze the general effect of sound type on pupil dilation we then ran a second GLM analysis using pupil dilation as the dependent variable and with sound type as the independent variable. A follow-up analysis looked at whether this effect was different between the pure sound condition and the simultaneous sound and brand logo presentation. To analyze this we ran a GLM analysis in which pupil dilation was used as the dependent variable, and with sound type (predictable, unpredictable), slide type (sound, sound + logo) and their interaction was used as independent variables, and with subject as random factor. Finally, we ran an explorative analysis of the effects of pupil dilation on preference ratings using preference rating as the dependent variable, and with pupil dilation as the independent variable.

Results

Unpredictable sounds were associated with lower preference ratings (mean ± SEM = 89.18 ± 0.09) when compared with predictable sounds (89.41 ± 0.1, \( t = 1.76, p = .039 \) one-tailed). Running an explorative regression analysis with preference score as the dependent variable and with sound type, brand category and sound type*brand category interaction, and with subject as random factor, we find a main effect of brand category (\( F = 2039.2, p < .0001 \)) and a sound type*brand category interaction (\( F = 190.4, p < .0001 \)), but no longer any main effect of sound type (\( F = 0.2, p = .643 \)).

Our first analysis of the main effect of sound type on pupil dilation demonstrated a significant effect where unpredictable sounds led to a significantly stronger pupil dilation response (mean ± SEM = 3.44 ± 0.007) than predictable sounds did (3.42 ± 0.007, \( t = 7.7, p < .0001 \)), as shown in Figure 5.

A follow-up analysis looked at whether the sound effect was different for the two stimulus conditions, where either the sound was presented alone, or where sound and logo was presented simultaneously. Here we found that besides the effect of sound type (\( F_{\text{predictable, unpredictable}} = 52.9, t = −7.3, p < .0001 \)) there was an additional strong effect of stimulus condition (\( F_{\text{sound, sound + image}} = 91348.0, t = 302.3, p < .0001 \)) but no interaction effect (\( F = 2.0, t = −1.41, p = .160 \); see also Figure 6). This effect is most likely caused by a pupil restriction to the increased brightness due to brand logo presentation.

Our final analysis focused on the relationship between pupil dilation and preference, by using preference ratings as the dependent variable.
pupil dilation the independent variable, and with subject as random factor in a GLM analysis, one analysis for the pure sound condition and one for the sound plus brand logo.

For the pure sound condition we find a negative linear relationship between pupil dilation and preference ($R^2 = 0.29$, $F = 40.6$, $\beta = -0.05$, $p < .0001$), suggesting that stronger pupil dilation was related to subsequent lower preference scores. For the condition with sound and logo, we find a positive linear effect ($R^2 = 0.19$, $F = 98.2$, $\beta = 0.02$, $p < .0001$). To further qualify this, we ran an additional post hoc analysis of the interaction between pupil size and epoch, and found this to be highly significant ($F = 17.7$, $p < .0001$).

**Discussion**

Two issues were sought to be resolved with Study 3. First, our choice of sounds closely mimicked the procedure used by Herry et al. (2007), in which unpredictable sounds evoked stronger emotional responses (assessed by the engagement of the amygdala, and the extent of avoidance behavior) compared with predictable sounds. Nevertheless, as our study used a different kind of stimuli and emotional responses (preference ratings), it was important to demonstrate that unpredictable sounds did evoke stronger emotional arousal than predictable sounds. Indeed, this was found, as unpredictable sounds produced larger pupil dilation responses compared with predictable sounds. Moreover, we were able to establish that this effect was present both when the pure tone was presented, and in the condition where subjects saw a brand logo and heard the sound. This finding suggests that an unpredictable sound evokes emotional arousal when presented alone, and that this effect spills over to the emotional processing of subsequently presented visual information. We believe that this arousal effect is responsible for the difference in brand logo preference, that is, that unpredictable sounds evoke an arousal response which leads to an initial negative emotional evaluation of simultaneously presented information in other visual domains.
It should be noted that Study 3 provides more information about the directionality of our behavioral results. While, on the one hand, both predictable and unpredictable sounds produced positive deflections in pupil dilation (i.e., an emotion response), we found that these responses were significantly stronger in the unpredictable condition. This finding suggests that the relative difference in preference, as seen in Study 1 and 2, is associated with a relatively stronger emotional response to unpredictable sounds.

Our second aim was to test the relationship between pupil dilation and preference. By running a regression analysis with pupil dilation as the independent variable and preference as the dependent variable, and using subject as a random factor, we find that the relationship is different depending on whether the sound is presented alone or together with the brand logo. In the condition with the single sound, we find a negative relationship between pupil size and brand logo preference. That is, the stronger the pupil response during this phase, the lower the subsequent brand logo preference. When analyzing the second condition, where sound and brand logo are presented simultaneously, we find an opposite effect. Here, larger pupil size in this period is related to more positive preference ratings. Our follow-up analysis furthermore demonstrated that this interaction effect between pupil dilation and stimulus condition was significant. This finding suggests that the negative effect of sound type on preference is most likely caused by the arousal response during the pure sound condition, and that, if anything, pupil dilation has no adverse effect on preference ratings when sounds are presented simultaneously with brand logos.

**General Discussion**

Judgments and choices have long been known to be affected by contextual factors such as uncertainty and ambiguity, and that even perceptual properties such as visual salience and mere repetition can lead to alterations in preference and judgments. However, our understanding of the exact mechanisms underlying these effects, and to what extent they can be induced through contextual stimuli alone, is still limited. The aim of this study was to test to what extent preferences would be influenced by simple contextual factors such as unpredictable sounds, and to what extent emotional responses could account for such effects. Based on recent studies that report increased aversion-related brain activation and avoidance behavior by rodents and humans to items associated with contextual unpredictability, we set out to test whether a similar set-up could affect preferences for cultural items. In particular, we tested whether sound predictability could operate as a key factor influencing preference for simultaneously presented complex visual items, such as novel brand logos and abstract art. Here, we report that preferences for visual stimuli belonging to different categories were negatively affected if items were simultaneously presented with unpredictable sounds, as opposed to a predictable sound. Furthermore, by using high resolution eye-tracking, we link these effects of sound on preference judgments to immediate changes in arousal, as indexed by pupil dilation responses.

Our findings provide novel insights into the mechanisms that contextual ambiguity and uncertainty can have on judgments and behavior. Our data bring together two strings of research on preference and judgments. First, behavioral economics have demonstrated that uncertainty and ambiguity, as explicit parts of decision contexts, increase aversion, and avoidance behaviors. Recent inclusions of physiological and neurobiological approaches have extended these findings by relating such behavioral effects to increased arousal (e.g., Bechara, Damasio & Damasio, 2000) and the engagement of brain structures involved in fear and aversion (Christopoulos et al., 2009). Here, our findings demonstrate that simple perceptual effects, such as the temporal ordering of meaningless sounds, can produce similar effects on arousal and subsequent judgments. We contend that these findings should be tested using stimulus predictability in other sensory domains, such as visual, tactile, and olfactory stimuli, when possible. Second, studies on the psychology of preference formation have long demonstrated different shades of the so-called mere exposure effect, in which stimulus repetition alone produces an increase in preference judgments (or, alternatively, a reduction of initial skepticism toward a novel object). Although our studies did not use repeated stimuli, they may still inform our understanding of the basic mechanisms of mere
exposure effects. As noted by Zajonc (1980, 2001) one explanation of the mere exposure effect is that the positive relationship between the number of presentations and preference may reflect a waning aversion, rather than a waxing of positive emotions. In this study, our demonstration that perceptual unpredictability leads to increased arousal and lower preference judgments could suggest that first impressions bear on an initial aversion response.

This still leaves open questions that remain to be answered. First, it is yet unknown whether simple contextual cues such as unpredictable sounds can affect value-based decision-making at higher levels such as gambling, multiattribute choices, and social dilemmas. Although these effects and limitations need to be studied better, it is still expected that any effect of ambiguity, as used here, will rely on the same basic emotional responses. To what extent emotional responses are induced by contextual ambiguity in all contexts, but are controlled by higher-order cognitive functions in certain situations but not others, remains to be seen.

References


Medicine, 31, 265–277. doi:10.1017/S0033291701003282


Received July 2, 2012
Revision received August 21, 2012
Accepted August 23, 2012