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Putting Salient Vocalizations in Context: Adults' Physiological Arousal to Emotive Cues in Domestic and External Environments

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ABSTRACT. Salient vocalizations are automatically processed and distinguished from emotionally irrelevant information. However, little is known of how contextual, gender and attentional variables interact to modulate physiological responses to salient emotive vocalizations. In this study, electrocardiogram (ECG) was utilized to investigate differences in peripheral nervous activity of men and women to infant cry (IC), infant laughter (IL) and adult cry (AC) in two different situational contexts: the domestic environment (DE) and the outside environment (OE). As the mental state of listeners can affect their response to vocalizations, a between-subject design was applied: one group was instructed to *imagine being inside the scenes* (Task 1: explicit task), and the other group was told to *look at the scenes* (Task 2: implicit task). Results revealed that females exhibited lower inter-beat interval (IBI) index in the OE condition, as compared to both males in OE and females in DE conditions, suggesting greater physiological arousal amongst females in response to vocalizations in an outside environment. Additionally, Task 1 revealed that males demonstrated higher Low Frequency/High Frequency (LFHF) index towards AC than IL. Task 2 showed the same association between these two sounds in females. The implicit task also elicited lower LFHF index in response to both IL and IC than control sound (CS), only amongst females. Findings highlight the important roles that contextual information and cognitive demand play in regulating physiological responses to salient emotive vocalizations. Integrated perspectives of physiological responses to emotive vocalizations that consider the influence of internal (adult mental states) and external (environment) contextual information will provide a better understanding of mechanisms underlying emotional processing of salient social cues.

Keywords: salient vocalization, infant cry, infant laugh, adult cry, ECG, context perception

1. INTRODUCTION

1.1 Salient Vocalizations and the Autonomic Nervous System (ANS)

In a world filled with noise that hardly ceases, the individual is assailed with salient and non-salient acoustic stimuli on an everyday basis. To distinguish salient emotive vocalizations from inessential cues, our attention effectively captures emotionally relevant information, while irrelevant ones are automatically filtered from the processing stream (Bestelmeyer, Maurage, Rouger, Latinus, & Belin, 2014; Frühholz, Ceravolo, & Grandjean, 2012; Paulmann & Kotz, 2008; Pinheiro et al., 2013). From among the wide spectrum of human acoustic events, those found to be perceived as most salient are positive and negative vocalizations produced by infants (Cecchini, Lai, & Langher, 2007; Newman, 2007; Soltis,

2004; Zeifman, 2001), as well as mature emotive sounds that convey distress (Vingerhoets & Cornelius, 2012).

The human cry, from infancy to adulthood, has evolved to represent a salient call of distress that signals a potentially threatening situation, urging a prompt response (Venuti et al., 2012; Messina et al., 2016; Tomkins and Tomkins, 1963). At birth, infants convey their needs and distress primarily by emotive sounds (crying, laughing, cooing), rendering them largely dependent on caregivers to sensitively perceive and respond to these salient vocal cues (Cecchini, Lai, & Langher, 2007; Newman, 2007; Soltis, 2004; Zeifman, 2001). Possessing a specific acoustic pattern (Esposito, Nakazawa, Venuti, & Bornstein, 2013; Esposito & Venuti, 2010), infant cry carries enormous emotional valence (Bell & Ainsworth, 1972; Soltis, 2004) that elicits caregiver proximity and triggers

caregiving behaviors (Bornstein et al., 2017; Bornstein, Costlow, Truzzi, & Esposito, 2016; Zeifman, 2001). Indeed, adults' responses to infant cry remain one of the most biologically adaptive human behaviors (Bornstein et al., 2017). Across the span of development, children acquire the ability to request for their needs, and audible crying reduces over time (Rebelsky and Black, 1972; Gekoski et al., 1983). In adulthood, although crying is a less frequent occurrence, it remains a salient vocalization that signals distress perhaps more so by its infrequency (Vingerhoets and Cornelius, 2012). Similar to infant cry, adult cry has been shown to initiate a call for action (Tomkins and Tomkins, 1963) and induce prosocial behaviors from others (Hill and Martin, 1997; Hendriks et al., 2008).

Besides distress cries, laughter, a positively valenced vocalization, is an important signal in social situations, creating an assured environment that facilitates social bonding (Fine & Apte, 1985). Laughter serves as an emotionally relevant stimulus (Johnstone et al., 2006), both in the context of adult-adult (Grammer & Eibl-Eibesfeldt, 1990) and parent-infant interactions (Papousek, & Papousek, 1986; Ziajka, 1981). Indeed, infant laughter evokes joyful emotions, enhances the quality of parenting behaviors (Bowlby, 1982; Groh & Roisman, 2009; Mendes et al., 2009), and activates reward centres in the brain (Kringelbach, 2005; Kringelbach et al., 2008; Strathearn et al., 2009).

Reactivity of the autonomic nervous system (ANS), a domain within the peripheral nervous system (PNS) that splits its control across two branches, sympathetic and parasympathetic divisions, is critical in prompting responses to cry (Joosen et al., 2013a; Moore et al., 2009). Infant cry elicits general physiological arousal in parents and non-parents alike, and in both males and females (Frodi et al. 1978; Groh & Roisman 2009). Enhanced autonomic physiological reactions to infant vocalizations, including increases in skin conductance (Frodi et al., 1978; Wiesenfeld et al. 1981, Esposito et al., 2017), heart rate, and blood pressure (Bleichfeld & Moely, 1984; Dalsant et al., 2015; Del Vecchio et al., 2009; Esposito et al., 2017; Frodi & Lamb, 1980; Furedy et al., 1989; Truzzi et al., 2017; Truzzi et al., 2018; Wiesenfeld et al., 1981; Zeifman, 2001) have been documented. Cry-specific physiological responses, contrasting typical infant cry to modified vocalizations (Esposito & Venuti, 2009; Esposito & Venuti, 2010; Sheinkopf et al., 2012) and atypical cry (Esposito et al., 2011, Esposito et al., 2012), have also been demonstrated.

1.2 Modulation of Physiological Responses

Given that salient vocalizations elicit instinctive physiological responses, the primary aim of this study is to investigate how task, gender, and context information moderate men's and women's physiological arousal in response to emotionally-relevant sounds. Although valence-specific autonomic patterning has been observed, where negative emotions often elicit greater arousal as compared to positive ones (Taylor, 1991), emotion scientists generally concur that physiological activation is not specific to single emotions, and that the association between emotion processing and autonomic nervous system (ANS) activity is modulated by moderator variables (Barrett, 2006). Autonomic responsivity towards salient vocalizations has been shown to be influenced by task, gender, and context.

Gender interacts with task to modulate autonomic response to salient vocalizations. For example, Rigo et al. (2016) found that women who were engaged in a self-referential decision task showed an automatic attention shift to infant cry, whereas men exhibited greater physiological response to female adult cries when they were engaged in a syllabic counting task. These findings suggest that physiological activities underlying responses to salient emotive sounds are possibly modulated by cognitive resource availability. Moderation of responsivity to salient sounds, particularly infant cry, by gender has been extensively explored (Rigo et al., 2016; Swain & Lorberbaum, 2008; De Pisapia et al., 2013; Boukydis & Burgess, 1982; Zeifman, 2003; Seifritz et al., 2003).

Knowledge about how external environmental factors, such as context, modulate adults' physiological reactivity in response to salient vocalizations remains scarce. More than two decades ago, Murray (1985) suggested that the context in which an infant's vocalization is heard, as well as cognitive appraisal of the emotive cue, greatly influence the selection of caregiving behaviors. Although limited in number, studies that investigate context effects show its force. In a study that investigated adults' eye movements in context perception, Bornstein et al. (2011) found that adults exhibited more fixations to congruent object-context scenes as compared to incongruent ones. Congruent scenes displayed natural object-context relations (e.g. tiger in nature) while incongruent scenes depicted contrasting relations (e.g. tiger in a residential area). The greater number of fixations to congruent scenes suggested that adults are more sensitive to environments with functional relationships.

Given that adults are presented daily with emotionally salient vocalizations in various environmental conditions, the significance of contextual information in governing adults' autonomic nervous system responses to these cues is starkly evident. However, no study has systematically investigated how a domestic environment moderates heart dynamics towards emotive sounds as compared to those generated by an environment outside of the domestic context. This study involves two tasks which only differ in the initial instructions provided: to *imagine being inside scenes* (Task 1: Explicit task) and simply *look at the scenes* (Task 2: Implicit task). We explored adults' responses to salient sounds (i.e. infant cry, infant laugh, adult cry) in the two environmental settings. Environments that fall under DE relate to close relationships and personal life and include locations within the private home setting (e.g. living room, kitchen); those in the OE category encompass external-oriented contexts outside of personal life, such as areas accessible to the public (e.g. bus stop, public television lounge).

Adults quickly extract objects from their contexts and selectively attend to them (Bornstein et al., 2011) with greater recruitment of top-down processes for selective verification of incongruent material. In line with this reasoning, we hypothesized that participants are more likely to exhibit greater physiological arousal towards salient vocalizations in the OE environment. The OE environment, which features public areas outside of the home environment, is arguably less congruent with infant vocalizations and adult cry (sound-context incongruence) than the domestic home setting of the DE environment (sound-context congruence). With respect to infant vocalizations, observational studies that have investigated parental response to infant cues are often conducted in the home environment (e.g. Joosen et al., 2013; Acebo & Thoman, 1995). The occurrence of adult cry is also inextricably linked to the domestic setting. Some of the most established variables linked to adult depression occur within the context of the family environment, including conflict, cohesion, nurturance and emotional warmth at home (Kaslow, Warner, John, & Brown, 1992; Rickel, Williams, & Loigman, 1988; Gerlsma, Snijders, Marijtje, van Duijn, & Emmelkamp, 1997). Palese et al. (2018) showed that 1 in 6 adult persons living in nursing homes cry daily. As such, due to less sound-context congruence in OE, we expected adults to require greater top-down processing of visual contextual and salient auditory information as compared to the DE condition.

We tested two hypotheses relating to task, gender, and context variables. First, due to less context-sound congruence present in the OE condition, we hypothesized that the physiological response to emotive vocalizations in the OE condition, as compared to DE, will be accompanied by a greater sympathetic nervous system response, indicated by lower IBI, RMSSD and pNN50 values. Second, previous studies have suggested that females may possess an enhanced perception of emotion as compared to males (Biele & Grabowska, 2006; Collignon et al., 2010; Donges et al., 2012; Kret & De Gelder, 2012; Li et al., 2008), and as such, we predict that the influence of context would be more prominent in females than males. To test our hypotheses, we measured the averaged interbeat-interval within a specified time window (IBI_{mean}), the number of times in which normalized R-R intervals exceeded a criterion in a considered time window (pNN50), the root mean square of successive differences (RMSSD), and an index of sympathovagal balance between the two nervous systems (LFHF).

2. MATERIALS AND METHODS

2.1 Participants

We recruited 33 nulliparous female adults (M age 21.39 ± 2.25 years) and 43 nulliparous male adults (M age 21.63 ± 2.23 years) through Nanyang Technological University. All participants were screened for any existing medical and psychiatric condition which could have interfered with physiological responsivity to the stimuli. The study was approved by the Psychology Program ethical committee of Nanyang Technological University, and participants gave their informed consent before participating.

2.2 Visual Stimuli

In each experimental session, participants were presented with 4 different images within the domestic environment (DE) and 4 different images from the outside environment (OE). Foreground images of persons performing 4 different actions were first sourced and obtained from a public online platform using Google Images Search Engine. The 4 foreground images consisted of people performing the following actions: 1) a woman cooking, 2) a woman texting on the phone, 3) a family of four watching the television, and 4) two women chatting with each other. The background images were obtained in the same manner. Each foreground image was

transposed on a background image from the DE condition and a different background image from the OE condition (**Figure 1**). The 4 DE background images were: 1) domestic kitchen, 2) entrance to an apartment, 3) living room, and 4) television room, and the 4 OE background images were: 1) commercial kitchen, 2) bus stop, 3) public television lounge, and 4) park. To reduce confounding variables, each foreground action picture was matched to a background in the DE and OE conditions as follows: 1) a woman cooking - DE: domestic kitchen; OE: commercial kitchen; 2) a woman texting on the phone - DE: entrance of an apartment, OE: bus stop; 3) a family of four watching the television - DE: television room, OE: public television lounge; and 4) two women chatting with each other - DE: living room, OE: park. Persons performing specific actions in the foreground image were of Asian Chinese ethnicity to reflect the majority ethnic group in Singapore. Foreground images were transposed to corresponding background images using Adobe Photoshop CC (www.adobe.com/sea/products/photoshop.html), and all images were further processed to control for brightness and resolution.

Figure 1. Visual Stimuli. Two examples of visual stimuli (actions: panel A (top) – a family of four watching the television; panel B (bottom) – two women chatting with each other) in DE and OE conditions. The same foreground of person(s) performing specific actions was superimposed upon DE and OE backgrounds. Four different actions were included in the experimental design: 1) a woman cooking - DE: domestic kitchen; OE: commercial kitchen; 2) a woman texting on the phone - DE: entrance of an apartment, OE: bus stop; 3) a family of four watching the television - DE: television room,

OE: public television lounge and 4) two women chatting with each other - DE: living room, OE: park.

2.3 Auditory Stimuli

During each test session, each participant was presented with 16 non-verbal sounds in total: a) 4 infant cries (IC; hunger cries from 1-year-old infants), b) 4 infant laughs (IL; from 1- to 2-year-olds), c) 4 female adult cries (AC), and d) 4 control sounds (CS). Human social vocalizations (i.e., IC, IL, AC) were retrieved from online public databases of sound files (Ljung & Wahlforss, 2008). Sound clips originated from separate individuals and were verified to be recorded from the respective populations in the public data repository. The same cry and laughter stimuli have been validated to evoke social distress and happiness, respectively, in previous studies (Esposito, Nakazawa, Venuti, & Bornstein, 2012; Truzzi et al., 2018; Esposito et al., 2017; Truzzi et al., 2017; Dalsant, Truzzi, Setoh, & Esposito, 2015).

For the present study, 5 sec of the original cry and laughter files were excerpted (sampling rates 44.1 kHz/32bit), background noise was removed, and sounds were matched for volume using Audacity 2.0.4 (<http://audacity.sourceforge.net>). To control for the acoustic structure of infant cries (Lorberbaum et al., 2002; Swain et al., 2008), 4 static white noise control sounds (CS) that mimicked the temporal pattern of infant cries was generated using Cool Edit Pro Version 1.2 Syntrillium Software (<http://www.syntrillium.com>). All sound stimuli were presented at a standardized volume of 20 arbitrary units through an earpiece, on an Acer notebook.

2.4 Experimental Design

The experiment consisted of two separate tasks to manipulate the cognitive demand and extent of mental engagement with the visual contextual stimuli being presented. In Task 1, participants were given an explicit task (i.e. instructed to “imagine being inside the scenes”), and in Task 2 participants were given an implicit task (i.e. instructed to “look at the images”). Instructions were displayed during the first 5 sec of each experimental session. Participants were randomized into one or the other of the two tasks, such that two independent samples were obtained. For each task, there were three independent variables: the between-factor variable was gender (2: male, female), and the within-factor variables were context (2: domestic environment, DE; outside environment, OE) and sound (4: infant cry, IC; infant laughter, IL; female adult cry, AC; control sound, CS). Individuals from each study

participated in 2 experimental sessions, with one test session being the OE condition, where the 4 images presented were from the OE category, and another test session being the DE condition, where the 4 images presented were from the DE category. The order in which participants engaged in DE and OE experimental sessions was counterbalanced. The effects of sound were investigated in each experimental session, such that all 4 sounds (IC, IL, AC, CS) were presented in both DE and OE conditions. To simulate real-life events, where adults commonly engage in activities before hearing salient social cues, participants were not instructed to explicitly attend to sound stimuli.

2.5 Experimental Sessions

Each experimental session, regardless of the DE or OE condition, comprised 16 trials. For each trial, one image was presented for a total duration of 25 sec. The onset of the auditory stimulus occurred after the image had been presented for 10 sec, accompanying the last 15 sec of the visual stimulus. The offset of both the image and sound was followed by a “+” cue, which was displayed at the centre of the blank screen. The recovery period lasted for 20 sec before the subsequent trial commenced. NIRSTim software was used to randomize the order of the images, such that each of the 4 images appeared four times over the course of one experimental session. The software randomized the order of the sound stimuli as well as the image-sound pairing in each trial (Figure 2).

2.6 Electrocardiogram (ECG) Data Acquisition

Participants’ cardiovascular activity throughout each experimental session was measured using an ECG belt device from Comftech (<http://www.comftech.com/>). The belt was strapped across the participant’s chest, and an ECG device, placed at the centre of the belt, allowed HR data to be wirelessly transferred to a tablet via Bluetooth using PhysioREC software.

2.7 Analysis

After screening for quality of ECG signal, data from 59 participants were eventually accepted for further analyses. Seventeen participants had to be excluded because of faulty signal recordings. First, ECG data of each participant were pre-processed by applying one high-pass filter to clear the noise and one low-pass filter to clear drifts in the signal. From the ECG signal, the R peaks were detected, and the inter-beat intervals (IBI) – the time between two successive R peaks (Malik, 1996) – were calculated using an automated customized algorithm generated using Python programming software (<https://www.python.org/>). Starting with calculation of the IBI, the following Heart Rate Variability (HRV) indices were extracted: (i) IBImean – the averaged IBI value in the considered time window (Stern et al., 2001), (ii) pNN50 – percentage of times in which the NN (normalized R-R intervals) intervals exceeded 50 milliseconds in the considered time window (Ewing, Nelson & Travis, 1984), and (iii) LFHF – the ratio between the power in the low frequency (LF) band, within 0.04 Hz and 0.15 Hz, and the high frequency (HF) band, within 0.15 Hz and 0.4 Hz, in the considered time window.

Regardless of the HRV index of interest, cardiac activity is first measured by capturing inter-beat intervals, which are indicative of the heart’s beat speed. Inter-beat intervals refer to the time taken between two R-peaks in the cardiac cycle (Malik, 1996). The electrocardiogram consists of a P-QRST waveform, and the R-peak within this waveform is a large spike in electrical activity caused by the rapid depolarization of the ventricles. The time taken between two R-peaks, measured in msec, is referred to as the inter-beat interval (Stern et al., 2001). Within a larger physiological context, the IBI is directly related to vagal firing rate, with increases in vagal firing accompanied by increases in IBI (Malik, 1996). Essentially, a greater parasympathetic response is associated with an increase in IBI. HRV indices derived from the calculated IBI provide information about the activation of the two branches of the Autonomic Nervous System, the parasympathetic and the

Figure 2. Experimental Design. Schematic diagram illustrating DE and OE conditions in task 1. In task 1, the instructions given were “Imagine to be inside the scenes” and in task 2, the instructions were replaced with “Look at the scenes” for 5s. Visual stimulus was presented from t=5s to t=30s. Auditory stimulus onset from t=15s to t=30s, accompanying the last 15 seconds of visual stimulus. All stimuli offset at t=30s and a recovery period, marked by a “+” cue, ensued from t=30s to t=50s. The next trial continued after the recovery period. Visual and auditory stimuli were presented in a randomized manner throughout the experiments.

sympathetic nervous systems. Lower averaged Heart Rate (indicated by higher IBI_{mean} and $pNN50$ indices) corresponds to a higher activation of the parasympathetic branch and a calmer state of the body. By contrast, lower values in these indices, together with higher values in the LFHF ratio, are associated with increased sympathetic arousal which underlies increased attention and promptness to action (Berntson, 1997; Bradley, 2009).

For each HRV index (IBI_{mean} , RMSSD, $pNN50$, LFHF) an ANOVA, with the HRV index as the dependent variable, participants' gender and task type (explicit, implicit) as a between-subjects factors, and contexts (DE, OE) and sounds (IC, IL, AC, CS) as within-subject factors, was conducted. Given the high number of comparisons conducted, Bonferroni correction was applied ($\alpha = 0.013$). Stimuli within the environmental conditions (i.e. a woman cooking, a woman texting on the phone, a family of four watching the television, two women chatting with each other) were aggregated within DE and OE contexts, respectively. Students' t -tests were performed as post-hoc analysis to examine single comparisons where the ANOVA exposed significant effects of a factor or of an interaction between factors.

3. RESULTS

3.1 Inter-beat Interval (IBI)

Analyses of Inter-beat Interval (IBI) revealed an effect of *gender*context* interaction ($F_{IBI}(1,53) = 6.71, p = .012, d = 0.69$). Specifically, females' IBI in OE condition were lower compared to males' IBI in the same context ($t(55) = 2.53, p = .014, d = 0.67$), and lower than females' IBI in the domestic context ($t(29) = 2.26, p = .03, d = 0.83$) [Figure 3]. However, these contrasts did not survive Bonferroni correction. No significant difference between types of tasks or sounds were observed.

Figure 3 (IBI): Plot of IBI Gender by Context Associations. Plot depicting significantly lower value of IBI index in females in the OE context, towards all sounds, compared to males in the OE context and to females in the DE context. * $p < .05$; ** $p < .01$; *** $p < .001$

3.2 LFHF

Analyses of LFHF revealed an effect of *task*gender*sound* interaction ($F_{LFHF}(3,159) = 4.23, p < .01, d = 0.55$) [Figure 4]. Specifically, in the explicit task, males' LFHF in response to adult cry was higher compared to males' LFHF in response to infant laughter ($t(13) = 2.61, p = .02, d = 1.01$). Also, in the explicit task, LFHF in response to white noise was higher in females compared to males ($t(28) = 2.25, p = .03, d = 0.60$). No difference in LFHF responses to different sounds within females was found [Figure 4a]. In contrast, in the implicit task, females' LFHF in response to infant laughter was lower compared to both females' LFHF in response to adult cry ($t(13) = 2.93, p = .012, d = 1.07$) and white noise ($t(13) = -4.00, p < .01, d = 1.46$). Additionally, females' LFHF in response to infant cry was lower compared to females' LFHF in response to white noise ($t(13) = -2.49, p = .03, d = 0.91$). No difference in LFHF responses to different sounds within males was found [Figure 4b]. However, among these contrasts, only the differences between females' LFHF in response to infant laughter and two other sounds – adult cry and white noise – survived Bonferroni correction. No significant effect of context was observed.

Figure 4 (LFHF): a) Plot of LFHF Gender by Sound Associations (Explicit Task). Plot depicting males' and females' LFHF average values in response to the different type of sounds in the explicit task b) **Plot of LFHF Gender by Sound Associations (Implicit Task).** Plot depicting males' and females' LFHF average values in response to the different type of sounds in the implicit task. * $p < .05$; ** $p < .01$; *** $p < .001$

3.3 RMSSD and PNN50

No main effect or interaction effect of task type, gender, context and sound has been found on RMSSD and PNN50.

4. DISCUSSION

In summary, this study revealed that females exhibited lower inter-beat interval (IBI) index in the outside of domestic environment (OE) condition, as compared to both males in OE and females in domestic environment (DE) conditions. This suggests evidence of greater physiological arousal in response to vocalizations in an outside environment, which is consistent with our first hypothesis that OE elicits higher sympathetic arousal than DE. Moreover, the gender-specific effect of this observation implies that females are potentially more sensitive in outside environments and public spaces, characteristic of the OE condition, as compared to males, which is congruous with our second hypothesis. Low frequency/high frequency (LFHF) analyses revealed distinct sound-specific patterns of physiological reactivity between males and females in the two instructional tasks. Task 1 (explicit task) showed that males demonstrated higher LFHF index towards adult cry (AC) than infant laughter (IL). Interestingly, Task 2 (implicit task) the same association between these two sounds in females. The implicit task also elicited lower LFHF index in response to both infant laughter (IL) and infant cry (IC) than control sound (CS), only amongst females. RMSSD and pNN50, two measures which have been found to be correlated with each other (Umetani, Singer, McCraty, & Atkinson, 1998), were not shown to be statistically significant. This suggests that other parameters of heart rate variability, namely beat-to-beat variance in heart rate, did not incur significant difference across gender, context, sound and task.

Independent of context and task, analyses did not reveal any significant difference between physiological activation of males and females towards the vocalizations. The present literature contains incongruous results, where, on one hand, numerous findings have shown that females exhibit greater sympathetic arousal to infant cries than males (i.e. Messina et al, 2016; De Pisapia et al., 2013), while, on the other hand, the opposite result has also been reported (Brewster, Nelson, McCanne, Lucas, & Milner, 1998). This inconsistency could potentially be explained by contextual and attentional modulation, in which pairing of infant distress vocalizations with specific instructions regulate physiological responsivity. Overall, our findings suggest the potential influence of context, gender, and task effects in generating physiological reactivity to salient social stimuli.

4.1 Greater Parasympathetic Activity in DE than OE Contexts

Inter-beat (R-R) Interval (IBI) is positively linearly associated with increased parasympathetic nervous system (PNS) activation (Stern et al., 2001). As such, a decrease in IBI is related to the speeding up of the cardiac cycle and an increase in sympathetic nervous system (SNS) activity. Results from this study showed a context effect, where there was greater parasympathetic activity in DE as compared to OE, and this difference was especially remarked within females. Porges (2007) claimed that a parasympathetic nervous system (PNS) response reflects a physiological regulatory component which is required for an individual to cope in the face of a challenging situation. Consequently, the DE environment might have allowed for greater control of affective arousal as compared to OE environments.

Extending the theory postulated by Bornstein et al. (2011), one possible explanation for this difference is that the external environment, when paired with salient vocalizations of infant and adult cry, as well as infant laughter, elicited less sound-context congruence as compared to the domestic home environment. As a result, greater selective processing could have been directed to both the visual scene and to salient vocalization to better process the incongruent sound-context pairings. In support of this postulation, a recent electrophysiology study conducted by Dudek and colleagues (2016) revealed that infant vocalizations heightened conflict processing during a STROOP task. Similarly, presentation of vocalizations in OE contexts might evoke greater conflict processing of incongruent material. Bridging this postulation to physiological responses, it is possible that enhanced selective processing of salient vocalizations in the OE context facilitated a greater increase in autonomic arousal. In comparison, the DE context, comprising scenes from the domestic environment, would have been more congruently paired with infant vocalizations and adult cries, and, as such, required less selective processing. Reduced attention to the salient vocalizations likely elicited less autonomic physiological response, allowing for greater control of affective arousal in the DE context.

Upon investigating females' and males' physiological responses separately, females showed greater parasympathetic activity in response to salient vocalizations in the DE as compared to the OE environment. However, there was no difference in males' PNS activity in DE and OE conditions. Overall, since the OE context was associated with more

physiological arousal than the DE, a lack of significance in males' PNS activity between the two conditions suggests that females are more sensitive and labile than males in public situations. This finding comports with previous literature reporting gender differences in stressful situations and specifically in response to distress cries. In a recent study that measured heart rate variability in response to acute psychosocial stressors, Brugnera and colleagues (2018) found that females reported higher levels of perceived stress and higher physiological arousal in response to acute psychosocial stressors, compared to males. Additionally, in an fMRI study of a social stress task, Lee and colleagues (2014) found that males exhibited greater recruitment of brain areas involved in inhibitory control and sensory awareness, and males reported lower subjective stress ratings as compared to females. Since males exhibit less autonomic response and self-reported stress towards social stressors, this might explain the limited modulating effect of context found in males, and a more pronounced effect in females.

4.2 Task and Gender Modulation of Physiological Arousal Towards Adult Cry and Infant Laughter

LFHF is a ratio that reflects the interplay of the sympathetic and parasympathetic branches of the nervous system – the sympathovagal balance between the two (Malliani, Pagani, Lombardi, & Cerutti, 1991; Malliani et al., 1997; Montano et al., 1994). While it may be tempting to infer the direction of physiological response from this ratio, previous studies have demonstrated that sympathovagal balance cannot be captured by a single number that assumes a linear relation between the two nervous system divisions and the frequency bands (Eckberg, 1997; Billman, 2013). The specific direction of nervous system activation, whether predominantly sympathetic or parasympathetic, cannot be deduced. Therefore, from the LFHF index obtained, one can only conclude that Task 1 revealed a different pattern of physiological reactivity, amongst males, towards adult cry (AC) than infant laughter (IL), while Task 2 demonstrated this same observation amongst females. The rapid distinction between infant and adult vocalizations corroborates with previous findings by Young and colleagues (2016), who found significantly different neural responses towards adult and infant vocalizations in non-parents, giving rise to the notion of a conserved “parenting instinct”.

However, sound-specific reactivity, which occurs in both males and females, appear to depend upon level of

cognitive engagement with environmental stimuli. The effect of “attended” and “unattended” attention is an old concept that was brought to light by Bryden (1982). Contemporary research exploring bimodal attention has since surfaced. In an fMRI study, Johnson and Zatorre (2005) revealed that increased brain activation occurred in areas corresponding to the modality that participants were told to attend to, in both unimodal and bimodal conditions. Comparing Task 1 and 2, greater cognitive demand was required to attend to the contextual information in Task 1 (i.e. *imagine to be inside the scenes*), which may have consequently led to differences in response to social sounds across genders (De Pisapia et al., 2013). Our findings on gender and task modulation in response to infant vocalization parallel that of De Pisapia and colleagues (2013), in which they demonstrated how the sound of a non-attended infant cry diminishes the activity of the default mode network in females but not in males. However, while the present study manipulated attention to contextual stimuli, De Pisapia et al. (2013) manipulated attention to the target infant vocalization. Interestingly, an interaction of gender and task nonetheless emerged in both instances, pointing at the possibility of differences in recruitment of attentional networks that may underlie distinct responses to infant vocalizations in males and females.

Finally, the valence of infant vocalization that males and females respond to is a noteworthy point of discussion. Task 2 revealed that, besides a specific reactivity to IL, females also depicted a different physiological responsivity towards both IL and IC, as compared to CS. These findings suggest that, in contrast to other sounds, females generally respond to infant vocalizations with a distinct physiological reactivity. On the contrary, males exhibited a different reactivity only to positive infant vocalization (IL), while this pattern of response was not discerned during presentation of negative infant stimuli (IC). The lack of prior caregiving experience in male non-parents is hypothesized to underscore this observed difference. Indeed, previous studies support this postulation, showing that the experiences acquired as a father led to significantly different responses to infant cries as compared to non-fathers (Seifritz et al., 2003; Storey et al., 2000).

5. CONCLUSIONS

This study sheds light on the processes involved in responding to salient vocalizations. Given that infant vocalizations and adult cry are essential social cues that act as a

vehicle to maintain caregiver proximity, establish parent-infant dyadic bonds, and signal social distress, the consequence of how different contextual information influences emotion processing is an important question that should be subsequently investigated. Although exploratory in our findings, this study raises the possibility of a modulating effect of attention, gender, and context, variables on adults' responses to emotive vocalizations. However, this study is not without its limitations. Little has been identified, let alone is known, about the specific contextual elements that catalyze distinct physiological responses to salient cues when presented in different contextual conditions. With findings from this study pointing at the indubitable role of context in influencing adaptive caregiving, the importance of further understanding the effect of different environments is resoundingly evident. Specifically, the mechanisms by which salient auditory cues and contextual information engage with our brain systems, cognitive constructs, memory, and emotion, remain to be unraveled. We believe this study has unveiled more about how attention, gender, and context variables interact with our biological systems to synergistically influence the way adults process and respond to salient social signals.

Conflict of Interest

The authors declare no conflict of interest.

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